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MINUTES

of the Third

EXPLOSIVES SAFETY SEMINAR

on

HIGH-ENERGY SOLID PROPELLANTS

Held at the

Mission Inn, Riverside, California

on

8-10 August 1961

332 711

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Armed Services Explosives Safety Board
Washington 25, D. C.

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PREFACE

Most of the discussion at the Seminar required no security classification. Certain discussions were classified "Confidential." Each page of these minutes has been stamped to indicate whether or not it contains "Confidential" information or is "Unclassified."

Participants were encouraged to present their own viewpoints. In some cases speakers described practices which differed from those in common use in the explosives industry. The inclusion of such comments in these minutes does not imply that they represent the viewpoint of the Armed Services Explosives Safety Board.

Further exchange of information on how to prevent explosive accidents is encouraged. It is suggested that any questions on portions of discussions be directed to the appropriate speakers, or their sponsoring agencies, rather than to the Armed Services Explosives Safety Board. This will expedite answers and will promote direct exchange of information between principals, which can be so effective in promoting safety.

Please advise the Armed Services Explosives Safety Board of any corrections to be made in these minutes, and errata sheets will be prepared.

The contribution to the cause of promoting explosives safety, by those who devoted valuable time and effort to this Seminar, is very much appreciated.

A. W. HAMILTON
Colonel, OC, USA
Chairman, Armed Services Explosives
Safety Board

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Minutes of the

Third Annual

EXPLOSIVES SAFETY SEMINAR ON HIGH ENERGY SOLID PROPELLANTS

Mission Inn
Riverside, California

8-10 August 1961

Sponsor

Armed Services Explosives Safety Board

Host

United States Air Force

Col. A. W. Hamilton, OC, USA, Chairman, ASESB: General Griffith, distinguished guests, gentlemen, I'm Colonel Hamilton, the Chairman of the Armed Services Explosives Safety Board, the agency which sponsors these meetings. My job today will be to act as moderator and to introduce the speakers. I'm glad to see so many familiar faces here, because it means that a lot of you who attended the previous meetings at the Naval Propellant Plant and at Redstone Arsenal have seen fit to come back for more. This year our host is the United States Air Force. It's a pleasure to introduce the keynoter of this conference, the Deputy Inspector General for Safety, Major General Perry B. Griffith.

Major General Perry B. Griffith, USAF, Deputy Inspector General for Safety, U. S. Air Force: Thank you very much Col. Hamilton. Good morning. The Air Force appreciates the opportunity to host the DOD-Industry Explosives Safety Seminar on High Energy Solid Propellants and my staff and I welcome you. If we can be of any assistance, feel free to call on us, not only during this seminar but after you return to your respective offices and plants. Since I have the Air Force responsibility for safety policies and procedures, you can see why I subscribe to the philosophy that the exchange of accident prevention data, techniques, and procedures must be continuous, aggressive, effective, and futuristic. To this end, Colonel Tubbs, my Director of Ground Safety, has included in the handout material some information which may be of assistance to you in channeling your future communications to the appropriate Air Staff safety office. Along that line and in the interest of promoting a better understanding of the Air Force safety program, I would like to review quickly my safety organization. I am one of three Deputy Inspectors General directly responsible to Lieutenant General Joseph F. Carroll, The Inspector General of the Air Force. He, in turn, answers directly to the Chief of Staff, General LeMay. Thus, our organization at nearby Norton Air Force Base is a part of Headquarters, U. S. Air Force, but fortunately we are decentralized here in California even though we are a Pentagon level organization. After having spent six years there, I think this is a pretty good break for me. To accomplish this worldwide mission we have four directorates - one each for Flight Safety, Ground Safety which includes the Explosives Safety Division, Missile Safety, and Nuclear Safety - and three special supporting Assistants - Life Sciences, Education and Training, and Records and Statistics. In looking over the attendance roster, I noted that there are approximately 25 industrial organizations represented and I shant go into this because you probably know a lot more about it than I do but I am delighted personally to see the across-the-board broad scope coverage that we have for the conference. Another observation is that Colonel Tubbs, my Director of Ground Safety, informs me that a cross-section analysis of the experience of the individuals represented in this room covers about 3,000 man years in explosives safety, maintenance operations, manufacture and allied functions. And that's a lot of time even though this fellow did go 435,000 miles in 25 hours yesterday. Of course, the primary objective of

this meeting is to exchange ideas, information and procedures from which can be developed a completely harmonious and constructive program of accident prevention. As you all know rapid advancement in development, production, storage, and use of present and future high energy solid propellants has introduced a variety of complex and unique hazards, and will continue to create them. These hazards include blast, seismic shock, fragmentation, dispersement of incendiary material, thermal radiation, toxicity, fire, and noise. The Services, Government agencies, and industry are equally responsible for developing ways and means to eliminate or control these hazards to an acceptable, realistic level, consistent with our operational missions and moral obligation for the general welfare of adjacent agricultural, industrial, and residential areas. If one or more of you can prevent a future major accident through knowledge and information exchanged at this seminar, the time and effort will have been well spent. After all, one accident with the high energy solid propellants with which we are dealing today may well be the difference in the development and deployment of an operational system, the award of a contract, or the factor which changes the company's ledger entries from black to red. And in addition to these obligations and responsibilities which I have mentioned, I would like to recall your attention to President Kennedy's 28 March 1961 acceptance speech in which he stated, "Any potential aggressor contemplating an attack on any part of the free world with any kind of weapon, conventional or nuclear, must know that our response will be suitable, selective, swift, and effective." Your contributions in accident prevention during development, production, transportation, handling, and use of high energy solid propellants, in my opinion, will have a positive, long-range effect on the conservation of our production, resources, combat capability, and responsiveness, which are essential in maintaining the President's policy. I personally would like to express my appreciation for your attendance at this seminar, and I will be looking forward to the benefits to be gained hereby. Again, the Air Force considers it a privilege to be the host for your Explosives Safety Seminar and I hope you all get a lot out of it. Thank you very much.

Col. Hamilton: Thank you very much General Griffith. Gentlemen, our next speaker is well known to all of you old hands in the explosives industry. For about 40 years he headed smokeless powder operations for the Hercules Powder Company. He has retired from there, but he is about the most active retired man that I know. He served as a Deputy Assistant Secretary of the Army and now, in addition to jobs as consultant to the Secretary of the Army and consultant to the Armed Services Explosives Safety Board, he is the Vice President of the American Ordnance Association in charge of all of their technical committees. It's a pleasure to present Mr. Henry Marsh.

Mr. Henry Marsh, Vice President, American Ordnance Association: Gentlemen. It's a real privilege for me to be here and have a chance to say something to you all at this start of the third of these safety seminars. It was

my pleasure to have worked with the Safety Board in the original concept of this idea. The fact that so many of you have come to the third one is to my mind the best proof that there is something pretty sound in this idea and that's why you're here. One of the things that I have said before and would like to repeat here - i.e., there have been times when some corporations have become so concerned about their proprietary rights that they have been hesitant to speak up and give information that might prevent an accident. I'm all for your protecting your proprietary rights, understand that, but please please don't let this interfere with the passing out of information here for the benefit of all of us in this game. Don't hold back on any information that might save a life. This I hope you will do, each of you. In this game there are many people who up to a few years back had nothing to do with explosives who are now very active in this rapidly changing technology period of ours and those newcomers can gain something from meeting with the old-timers that have had a little more experience in conventional explosives and both groups can work with one another with all these fantastic new exotic types of propellant that we are getting into now. The present situation worldwide is something that calls for some extra effort for us to do all that we can do to be well prepared and our best defense is adequate preparedness. This is our best insurance to keep the peace. It's very kind of Colonel Hamilton to let me say a little bit about this organization of which I am the Vice President. There are doubtless some of you that don't know the American Ordnance Association, a non-partisan, non-profit, and non-political organization. One of its primary functions is the organization of technical committees and divisions which serve the Government, all the Armed Services, by being given problems that are of concern to the Service and being able to give them some sound advice and industry's opinion about the producibility or the soundness of design and things of that sort. These people who were involved in ordnance production, design, maintenance, etc. during WW II are I think familiar with AOA. But there are some of these new folks who may not even know about us and my remarks are primarily addressed to them. I can look around and see a good many of the people who serve on my AOA technical committees and help us in this job. Might I just ask so that I have a little better feel for this particular group, how many of the people in the room, either are members of the AOA or as Government contacts, serve with the AOA technical divisions and committees? Well to that group, I would like to make a little remark that the efficiency of our work to help the Services depends on the broad coverage of industry working in the technical divisions and while we have many people who are members of the organization, they have not applied for and become active in the technical divisions. There are about 10% of the membership who share in that fashion. If there is a field of ordnance in which you have particular skill, we would appreciate you coming to us and asking for service in one of the technical divisions and committees so that our information will be of most help. To those others who do not now belong to the

association, may I urge to you that you join. It costs so little, amongst other things, the membership brings to you the Ordnance Magazine which is recognized worldwide as the most authoritative publication available today on ordnance matters. The opportunity will come to you all to serve on the technical committees and take part in those activities as well. At these meetings the Government informs us on new developments and the problems that they have there. We in turn consider these and do our best to give them an intelligent answer. Take a look if you can stand it and I do have some forms and any of you that are not now members, I should be most delighted to let you have a form and get you to join the American Ordnance Assoc. It's a delight to be here and to see so many old friends.

Col. Hamilton: Thank you Mr. Marsh. We have a very broad coverage in this room. Not only do we have Army, Navy and Air Force, we have the Interstate Commerce Commission, NASA, Bureau of Explosives and last but not least, just about the entire explosives industry of the United States. The exchange of information, as Mr. Marsh pointed out, can help towards saving lives and saving property that is very important to you and also very important to the defense of this country. Since we have here representatives of just about every large explosives organization in the United States and we're exchanging information, even though we do have the best of intentions, we have to be very careful that we don't do anything that anyone could even possibly interpret as violating the intent of anti-trust laws; which brings us to the subject of lawyers. Lawyers as you know are people with horns or people with wings depending on which side they represent. We have one here who works for the Secretary of the Army, who I think we can consider as being in the wings category because he's on our side and his sole purpose here is to keep us out of trouble. We hope for a very free exchange of information but if we should happen to touch any area that might possibly get any of us in trouble on anti-trust, then he's going to wave a flag and press a buzzer at that moment. It's a pleasure to introduce Mr. Don Miller of the Office of the General Counsel, Office, Secretary of the Army.

Mr. Donald B. Miller: The Attorney General has held that activities of committees such as this Seminar are subject to the anti-trust laws and persons participating are not immune from prosecution under such laws. The Department of Justice takes the position that it retains complete freedom to institute proceedings, either civil or criminal, or both, in the event it considers the actions of any such committee meetings are being used to unlawful private ends. The Attorney General has established certain criteria which are intended to minimize the possibility of violating the anti-trust laws and these standards have been incorporated in Department of Defense regulations. The Assistant Secretary of the Army, who has been assigned responsibility for supervision of the activities of the Armed Services Explosives Safety Board,

considers this Seminar to be of great importance, and as an additional safeguard, in order to provide the maximum possible protection to all participants, he has requested the General Counsel of the Army to furnish counsel. I am Assistant to the General Counsel and have been designated to represent the Office of the General Counsel, Department of the Army, to provide counsel at this Seminar. The agenda has been made sufficiently broad so that any matter related to the topics under consideration can be freely discussed. My presence at this Seminar is not intended to limit, in any manner, full and free discussion of the topics under consideration but rather to promote such discussions. My primary purpose in attending this Seminar is to protect both Government personnel and industry members from the inadvertent consideration of any subject which might bring the Seminar activities within some aspect of the anti-trust laws. In addition I would like to mention that this year there has been a renewed interest in the provisions of the anti-trust law and those of you who have been reading the newspaper can see why. President Kennedy has issued a proposed executive order entitled "Prescribing Regulations for the Formulation and Use of Advisory Committees." This proposed executive order which is now being coordinated with the various Governmental agencies in Washington is based on a 1950 letter of the Attorney General on which the Department of Army regulations have been based for many years. This letter has been the basis for Department of Defense regulations for the last three years. Accordingly, the executive order is very similar to the Department of Defense regulations, in many aspects it is word for word. In addition to the proposed executive order which is not yet in effect, we have a bill which has been introduced in Congress. This is H.R. 72 of the 7th Congress. This resolution was introduced by Mr. Seller and is called "A Bill to Amend the Clayton Act to Establish Standards for the Organization and Operation of Government Advisory Groups." This also is based on the 1950 letter of the Attorney General setting forth standards for meetings such as this we have here today. The seminar since its very beginning has been conducted in such a fine high standard with excellent knowledge and conduct by the moderator throughout that not only do we meet with the Defense regulations, we meet the provisions of the proposed executive order and we meet with the provisions of the proposed bill so the people in this room have absolutely nothing to fear, but I thought you'd like to know about the proposed executive order and the resolution in Congress so you can jot them down and go back to your General Counsel and he would know you were listening to the lawyer here.

Col. Hamilton: Gentlemen, at this time I would like to introduce three people, representatives of the Armed Services who will be here to answer questions involving what the Services are doing. Mr. Herbert Roylance, Navy; Mr. Jezek, Army; and Mr. Don Endsley, Air Force. At this time I'd like to mention that we all owe a lot to Mr. Endsley for all of the arrangements, in connection with these activities, here in

Riverside. Don Endsley has done a lot of work on this meeting and we appreciate it very much. At the Washington end Mr. Lowell has done a lot of work including putting together the agenda and handling all the paper work at that end and we all owe him a lot of thanks for his efforts. Thank you very much. The first of our technical subjects has been chosen to be first because it has a lot to do with why we are here. Mr. Brinkley has investigated more explosive accidents than anyone else that I know of. He's the Chief of the Investigation and Evaluation Division of the U. S. Army Ordnance Field Safety Office and he's going to discuss 'Accidents and Fires Involving Propellants.'

Mr. Brinkley: "Concern for man himself and his fate must always form the chief interest of all technical endeavor; never forget this in the midst of your diagrams and equations." This sounds like something a safety engineer would say; but actually, it was the great scientist, Albert Einstein. Regardless of who said it, this quotation expresses the theme of my talk.

In spite of our progress in designing accident prevention features into our equipment and facilities, PEOPLE still cause accidents. Man's behavior can not be accurately predicted in any given circumstances. Therefore, our efforts must be directed toward recognizing the hazards, controlling them if we can - and if they can not be controlled, protecting against them.

We must have a knowledge of what to expect of the explosives and propellants under various conditions if we are to work with them safely. Unfortunately, some of this knowledge is acquired through the medium of accidents, which involve the loss of life and property. Therefore, many safety precautions are born of an accident.

This sounds as if I were recommending accidents - the more accidents, the more we learn about safe operation. But I don't mean it that way. We can not afford the luxury of rebuilding facilities especially if they were not designed to withstand the explosive potential of the propellant being processed or tested. Nor can we afford to lose the critical equipment that may take months to replace. The loss of production may be even more critical and if there is a question of compromised safety, the circumstances could result in the loss of a contract, and have an adverse effect on the reputation of the company itself.

The first slide shows a large manufacturing plant in the process of going out of business. A series of explosions, involving 2500 pounds of explosives, has just occurred. In a few minutes, eleven employees will have died and 67 more will have been injured. In a few hours, 35 buildings will have been completely destroyed and others severely damaged. The plant had been working on an Army contract

involving a Class 10 explosive item. The company processed the item as Class 2. This accident cost a half-million dollars. Investigation revealed that the first explosion involved the Army item.

Slide 1

Slide 2

Several buildings stood here a few hours ago. All important operating buildings were destroyed. There wasn't enough left to start business again.

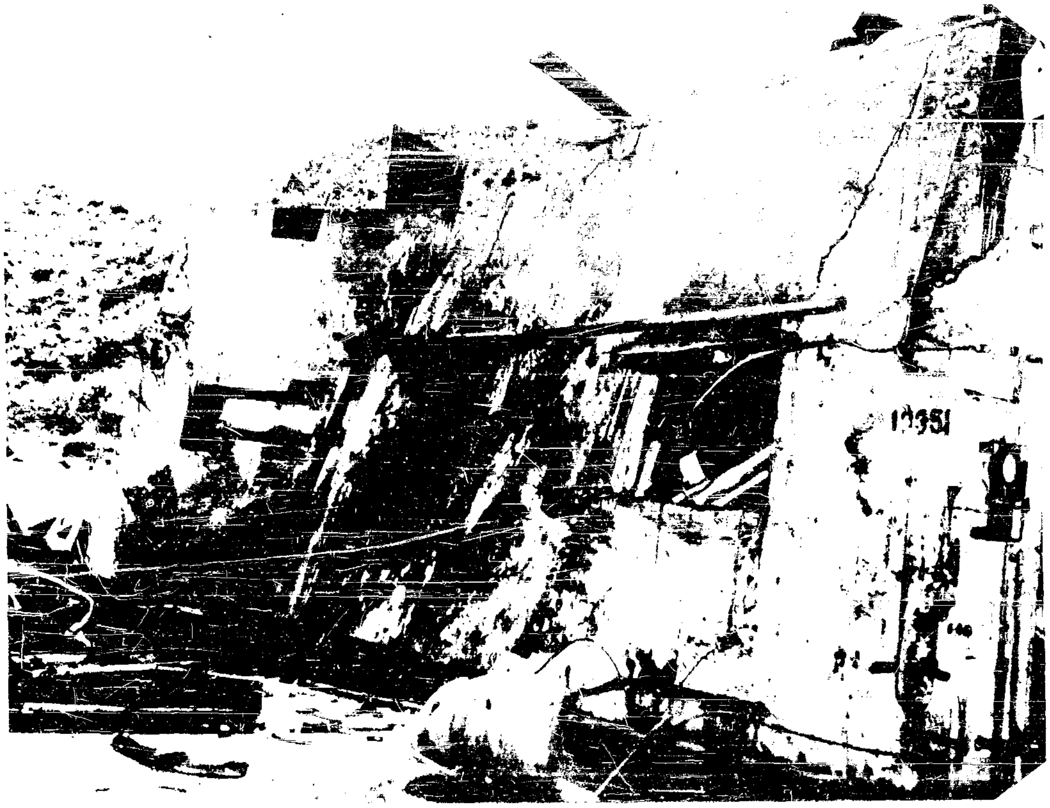
We safety people appreciate the fact that the trend in explosives manufacturing facilities is toward automation and complete protection for operating people. However, this ideal condition does not exist yet. From all indications it appears to be a long way off. Research and development is outdating propellant compositions, equipment and facilities faster than the industry can evaluate them for the necessary safety requirements. Because of this, the industry has suffered several costly explosions and fires in operations involving propellants during the past several years. Who in this room can say that his installation, company or laboratory will not be the next.

Some of the accidents have been the result of giving too much responsibility to personnel not adequately safety trained, or who lack sufficient operating experience. Today many of our engineers and technicians are stepping from the campuses to the laboratories and plants with little or no safety experience. Because of the rapid increase in missile and rocket development and the urgent need for manpower, many of these young men are soon in supervisory positions. In general, however, they are so interested in getting ahead that safety is not given due consideration. From a safety viewpoint, it is the blind leading the blind.

We don't realize the impact of a costly explosion or fire until it involves the operation for which we are directly responsible, and personnel we know, our company, or our installation - and our own careers.

Slide 3

You are now looking at a NIKE B missile containing JP4 fuel and nitric acid, ready for a static test at an Army installation. The missile is $7\frac{1}{2}$ feet from the 12" reinforced concrete wall which has two openings, one of which is covered with aluminum sheet. This wall is what the eight assigned engineers conducting the test depended on for protection. No one expected the unexpected. Certainly not an explosion. What happened? You guessed it.



Slide 4

An explosion. It occurred several seconds after an attempt to ignite the motors. The engineer assigned to a position facing the window at the right was killed. Several others in the test stand were injured. The concrete wall cracked in several places and the building received severe structural damage. Cost - $600,000.

Slide 5

Yes, this accident was an expensive lesson. However, it focused attention on deficiencies in existing test stands, and the lack of protection afforded to assigned personnel.

I am quite sure that many of you men who are responsible for hazardous operations have had lots of sleepless nights. If you are ever involved in an explosion or fire which results in loss of life or high property damage, your worries will be even worse. Could the accident have been prevented if -----------? These worries are disheartening and depressive. I know.

This brings to mind the tragic career of a young ammunition inspector who worked for me at Letterkenny Ordnance Depot in 1946. He asked me to transfer him to Okinawa. It meant an immediate promotion for him and he wanted the experience, so I transferred him. Several months later, I heard that he had committed suicide. I learned the circumstances from other inspectors with whom he worked. A barge loaded with ammunition exploded during unloading and a large number of natives were killed. The inspector was not present when the explosion occurred, but he felt that if he had been, the explosion might have been prevented, and that he was in some way responsible for the tragedy. This self-blame led him to take his life.

For more than ten years, I have been investigating serious explosives accidents for the Ordnance Corps. The thing that has impressed me more than anything else is the lack of due respect for basic safety principles by some highly technical personnel. They seem to be too willing to gamble.

A safety engineer cannot understand such complacency on the part of the professional, a man who has undoubtedly spent a small fortune, and years of his life to get to his present position. In one second, however, he will gamble -- and stands a good chance to lose all he ever had. No man has a right to shorten life, even if it is his own.

The past year has highlighted several areas which, in my opinion, require increased attention if we are to maintain our present excellent safety record. As I see it, these are some of the major trouble spots: Inadequate protection for personnel, lack of sufficient safety training, increase in explosive potential and sensitivity of new chemicals, use of outdated equipment and facilities, poor communication of information between research and development laboratories.

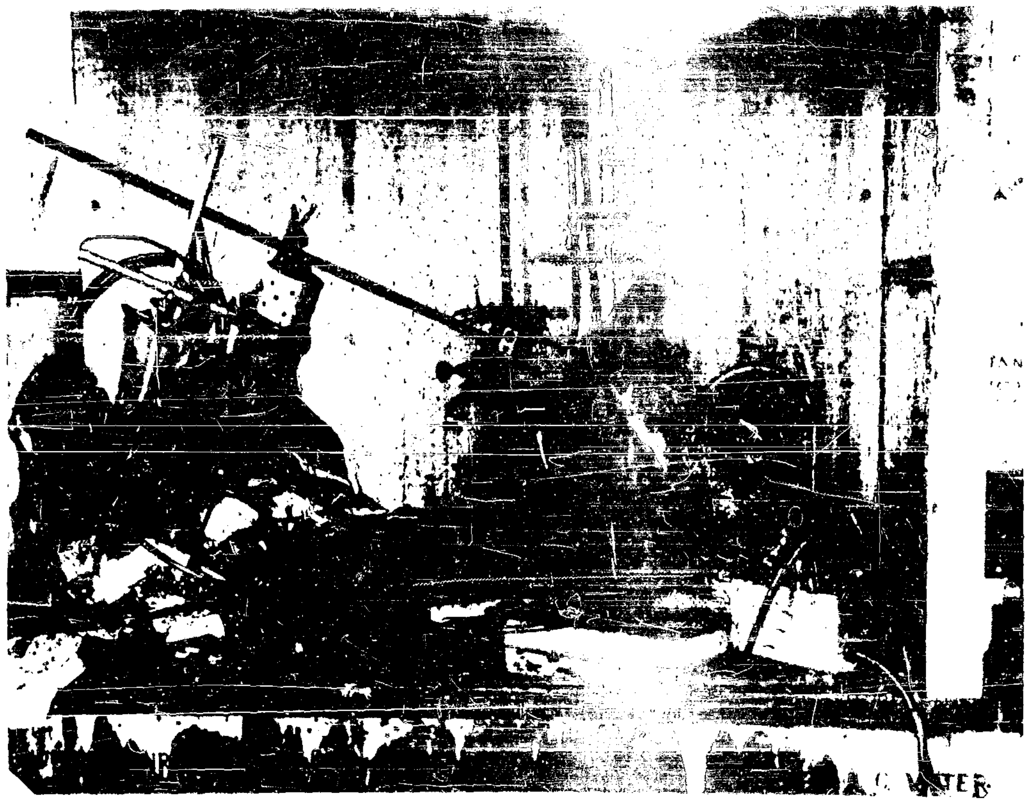
You can see how these items are all dangerous in the explosives business. Couple them with complacent, inexperienced, or careless persons - whether they be management, supervisors or employees - and it spells trouble - bad trouble.

Some may say, but, that wouldn't happen at our plant. For those, I will let experience speak for itself. We all know there is no substitute for it. I'm going to show you several accidents and fires involving high energy propellants, which have been costly from a personnel, production, and property standpoint. You can make up your own minds about them.

Perhaps you remember that, during the last seminar, Dr. Shuey of Rohm & Haas expressed concern for the scientist assigned to researching new chemicals. His fears were not groundless. Just one Army Ordnance installation experienced 26 laboratory fires and explosions in the past three years. There were several serious injuries and deaths.

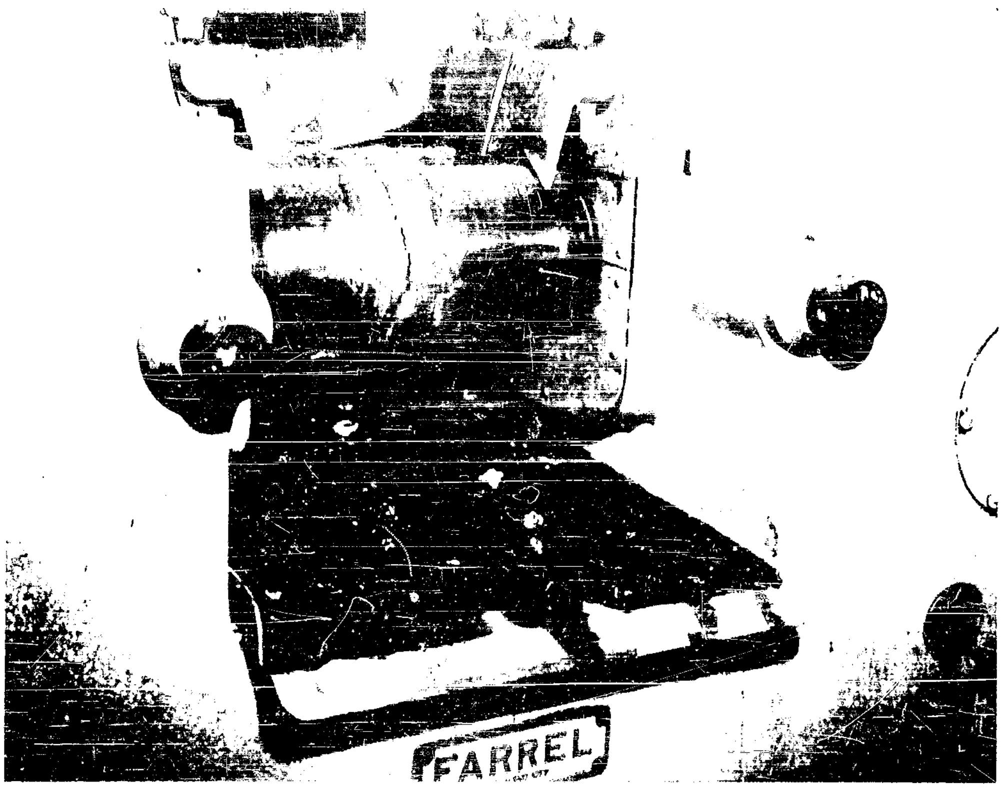
Slide 6 shows the physical damage that resulted from a simple act. A chemist poured 90% hydrogen peroxide into a laboratory sink. However, the drain pipe was connected to that from another sink, on the same side of a trap. At some previous time, unsymmetrical dimethylhydrazine - old UDMH - had been poured into the other sink. Apparently some UDMH remained in the trap and reacted violently with the hydrogen peroxide. The explosion killed the chemist.

Slide 6



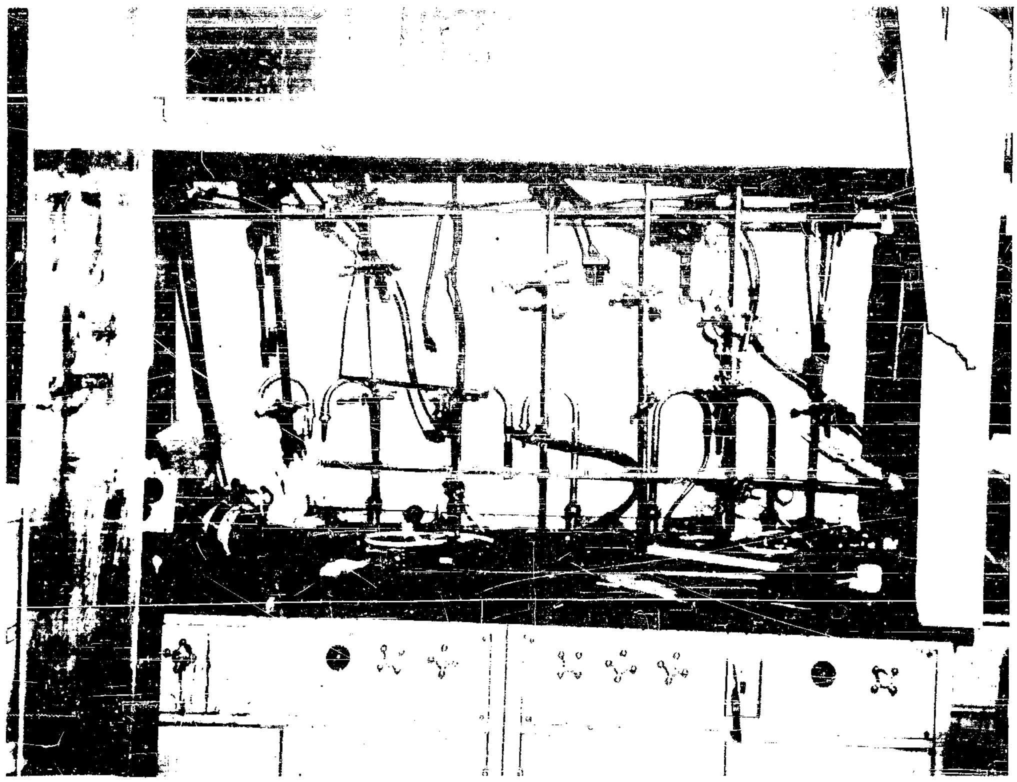
Slide [illegible]

Only two grams of a classified [illegible] mixture did this during a vacuum stability test. [illegible] minutes of heating the sample in the oil bath, the che[illegible] [illegible]ved excessive gas evolution. He raised the operation [illegible] his protection -- to remove the test sample. Then [illegible] the chemist and his technician received multiple [illegible] from the oil.



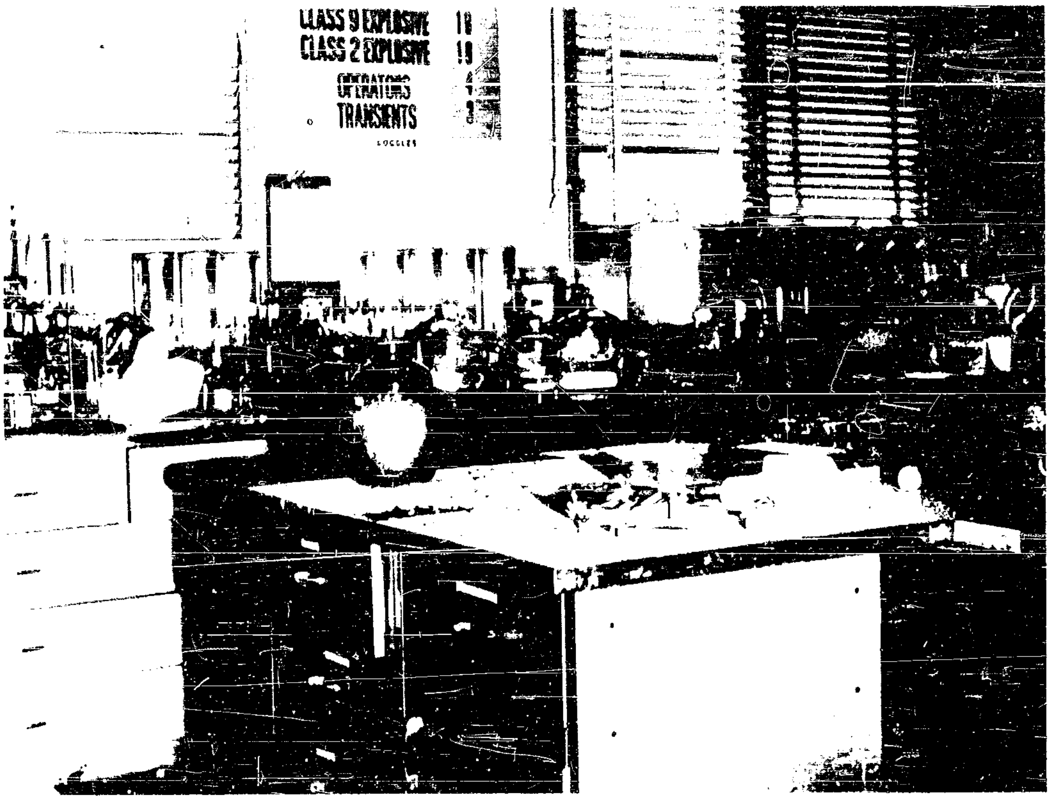
Slide 8

Two chemists were mixing a high energy propellant by remote control on this differential roll mill. A detonation occurred when one of them attempted to score the material on the roll with a spatula, although he knew the propellant was extremely sensitive. Both chemists were severely injured.



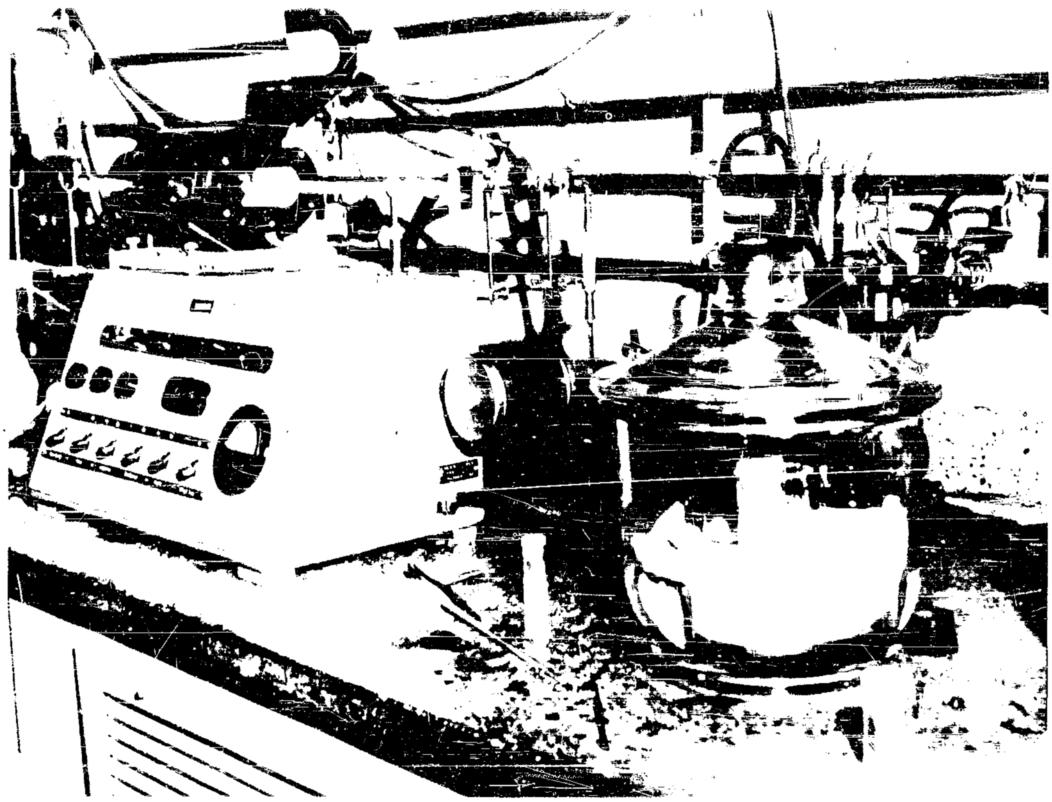
Slide 9

A technician was preparing 629 grams of a research chemical at this location when an explosion occurred. He was seriously injured. Investigation revealed that he had deviated from the standard procedure. He had failed in introducing the [illegible] into the solution.



Slide 10

This is the location where a technician was using a mortar and pestle to pulverize three or four grams of a classified solid high energy oxidizer. An explosion occurred which resulted in severe injuries to his hands and multiple cuts on his face. Eye protection and gloves prevented more serious injuries. Note the depression in the 18-gage, stainless steel table. Information regarding similar experiences by other R&D laboratories may have prevented this accident.

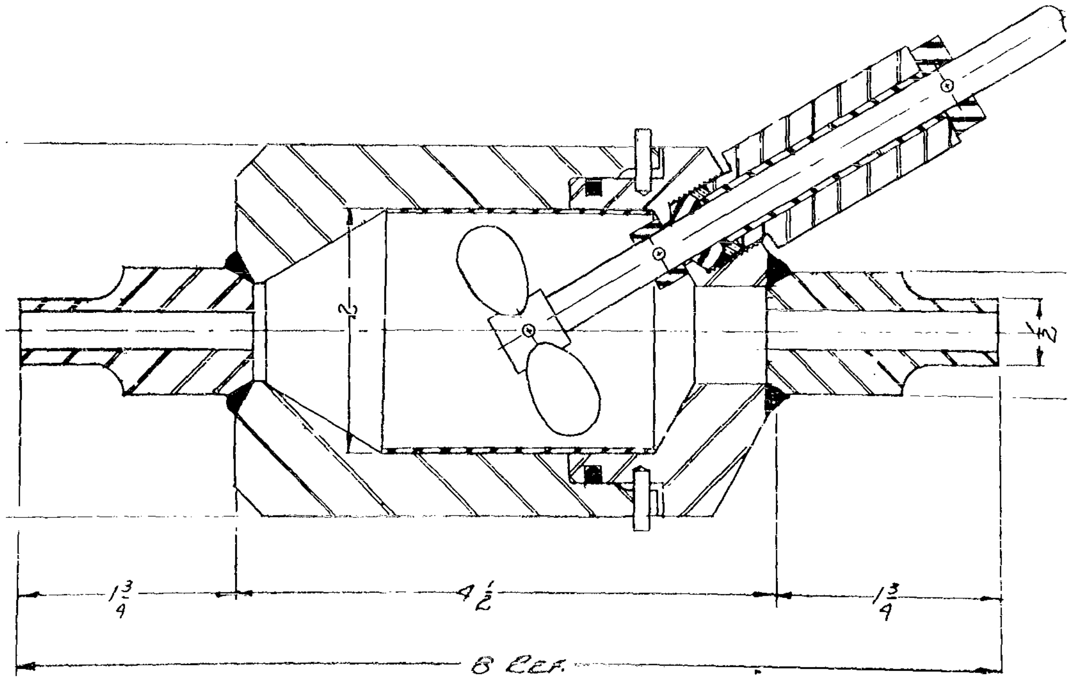


Slide 11

Here is the result of a situation that is becoming all too common. A classified chemical was being researched for the purpose of getting a patent on it. The only test that had been made to determine it's explosive characteristics was a drop test. A chemist obtained a two-gram sample from refrigerated storage to make an analysis. As he removed the stopper from the sample container, an explosion occurred. It is tragic that the chemist had, for some reason, taken off his safety glasses. He now has only one eye.

Slide 12

In this room, the industry experienced one of its most serious research and development accidents. During the pumping of a composite propellant from a mixer into a JATO motor located in the adjacent bay, there was an explosion. It occurred in a small in-line mixer used for incorporating a catalyst into the propellant. The mixer was designed and constructed by the project engineer and had not been reviewed for safety. It blew into pieces, several of which struck and killed the assigned technician.. The project engineer himself was severely burned.



CROSS SECTION OF MODIFIED IN-LINE MIXER

Slide 13

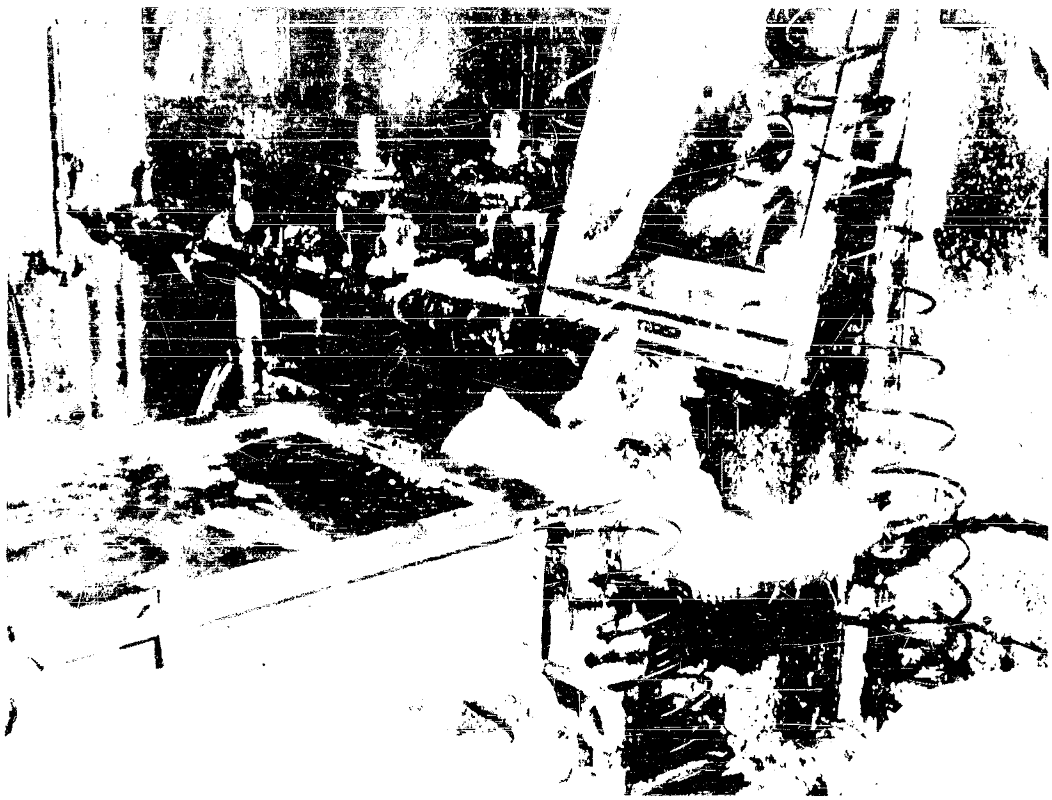
This picture shows the construction details of the in-line mixer. It had a capacity of one-half pint. The probable cause of the explosion was frictional heat or pinching of the propellant. The recovered shaft was observed to be slightly scored. This accident indicates the need for management review and approval of all new or modified equipment used in explosives operations.

Every research and development project carries a new risk. It is the responsibility of the supervising scientist who initiates the research to determine the risk, it's relative importance and to provide adequate safeguards. We always come back to one of the basic concepts of good safety programs. Safety must be planned and engineered into every job. This is often overlooked in R&D projects.

The Ordnance Corps has experienced a number of costly mixer accidents. They have cost the Government over one million dollars, some injuries, and lost production. Again, we have been more than lucky, as some of you are well aware.

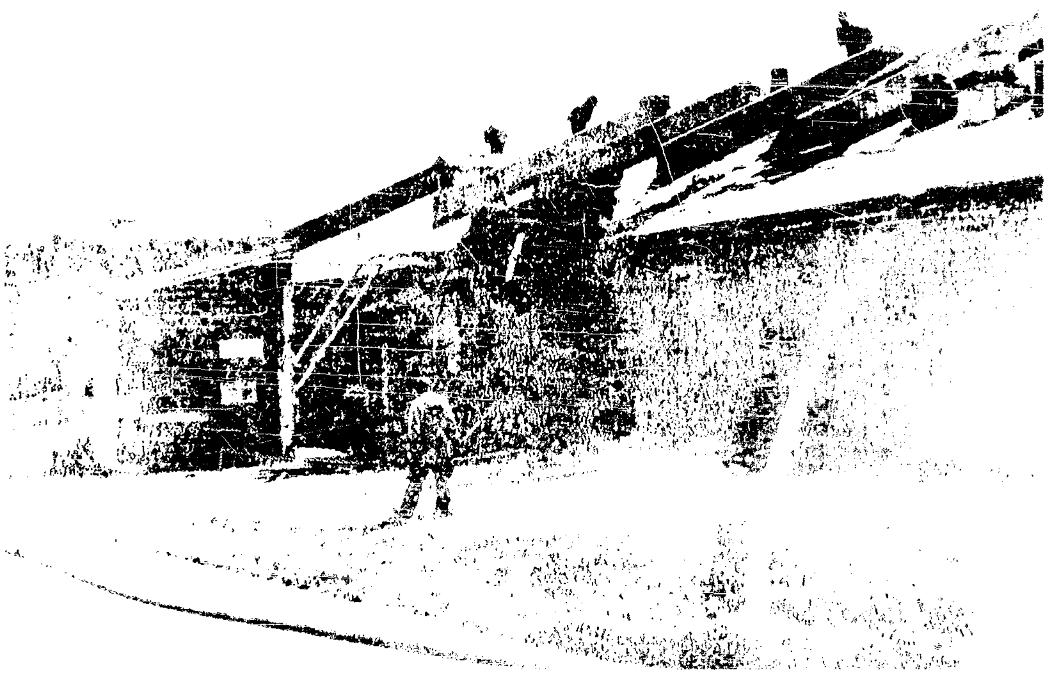
Who would care to gamble that a mixer accident will result in a fire instead of an explosion. Many researchers state that every explosion is preceded by a fire. The truth of this depends on many conditions existing at the time.

Let's review some of our experiences with mixers.



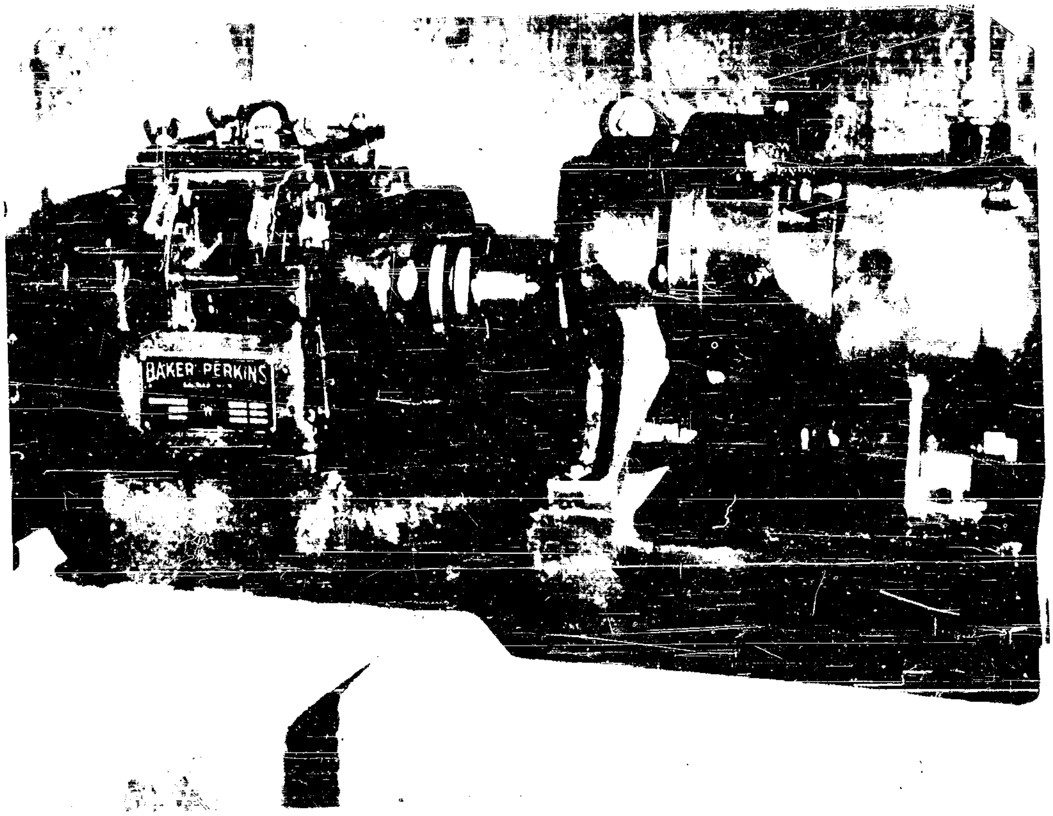
Slide 14

This is a 20-gallon Baker-Perskins mixer in which 177 pounds of propellant flashed. The accident resulted in several injuries and property damage of about $19,000. Two substantial dividing walls and a 6' corridor separated the mixer controls from the mixer bay. The mixer lid weighed nearly 300 lbs. and was closed at the time of the accident. A piece of stainless steel screen was found in this mixer. It had been subjected to impact from the blades.



Slide 13

Note the condition of this building after the explosion and fire. It was designed for research and development projects, and not for production-scale operations. Fatalities and more extensive damages would have resulted if a detonation had taken place.

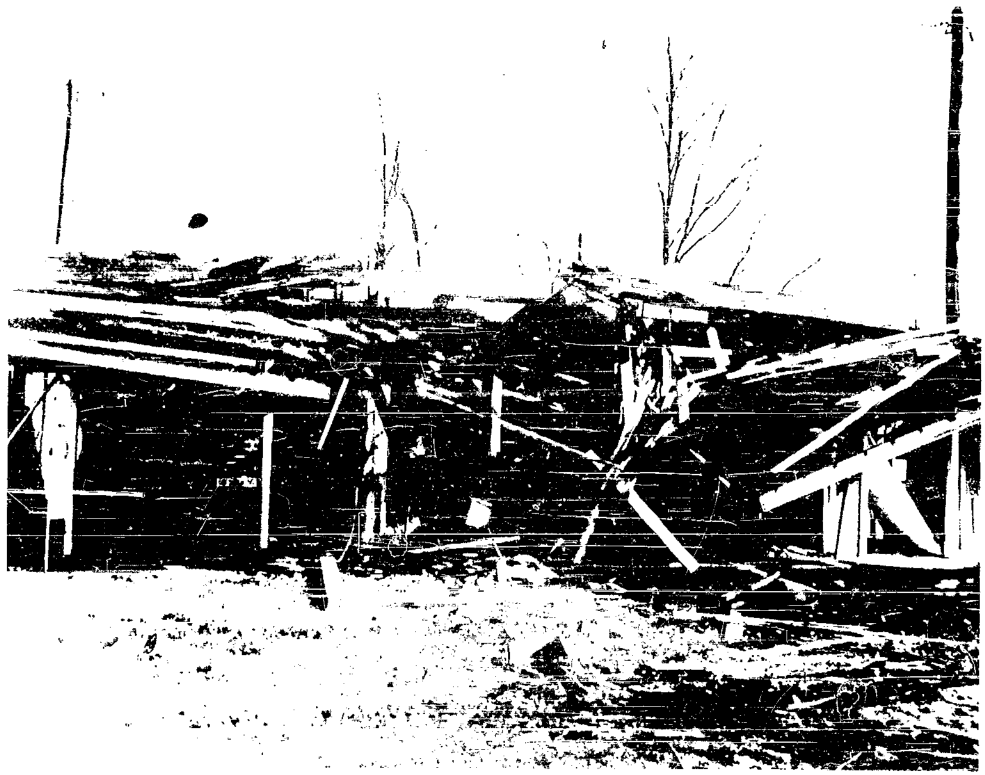


Slide 16

In this accident, we can get a before and after effect. Let's take a three-quart sigma-blade laboratory mixer like this and load it with ten pounds of a classified solid propellant. Now we will let it operate three to five minutes. Note that the mixer lid is securely fastened. Operations are by remote control.

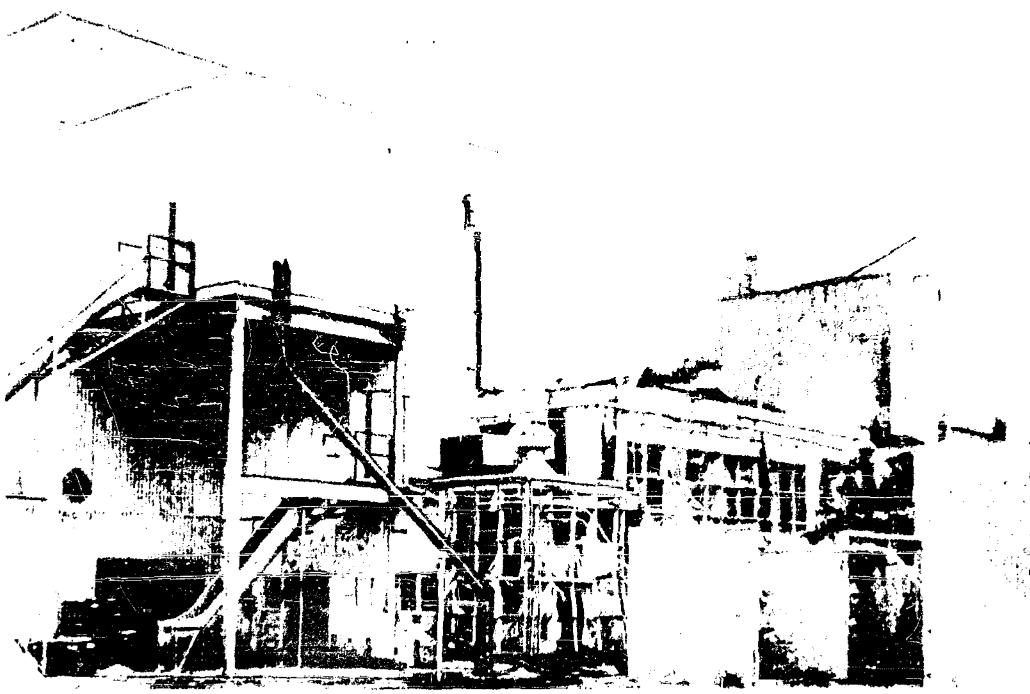
Slide 17

This is the condition of the mixing bay after our mixer exploded. The 12" reinforced concrete wall is cracked in several places. All equipment in the bay has been destroyed. Foreign material is suspected as one probable cause. Friction on the bearing surfaces is another.



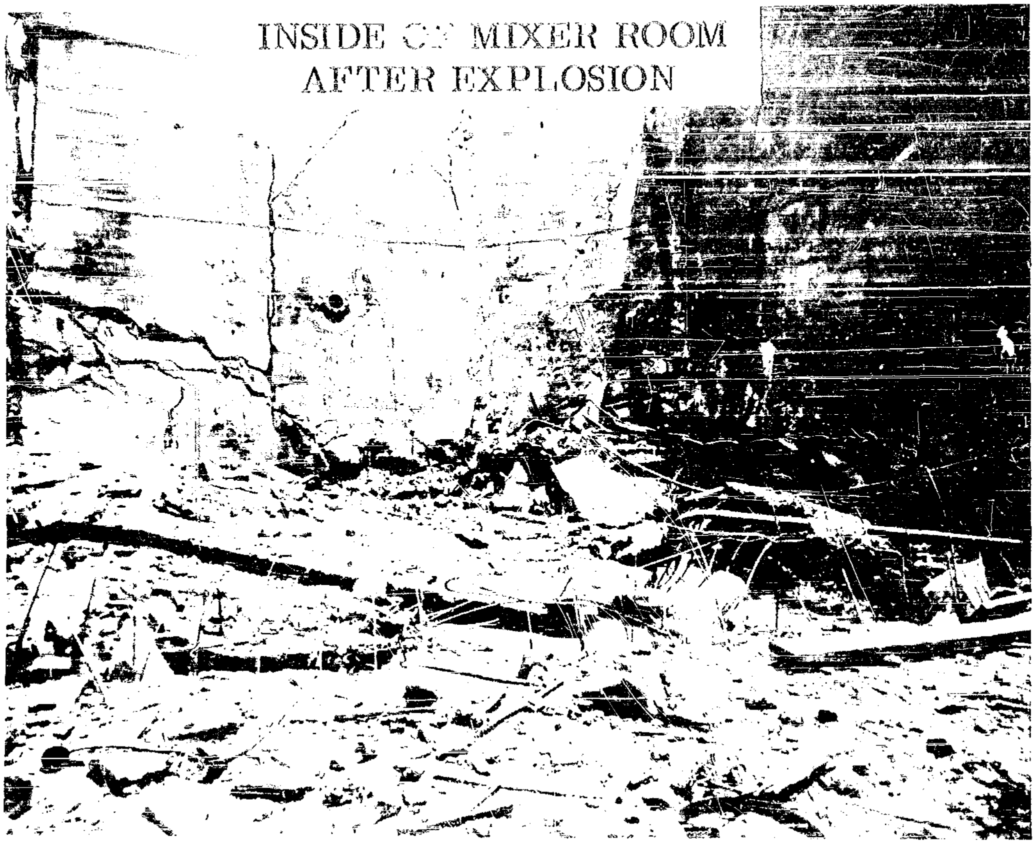
Slide 18

The building damage was around $22,000. This type of structure, with a continuous roof over the bays, suffers excessive damage if an explosion occurs.



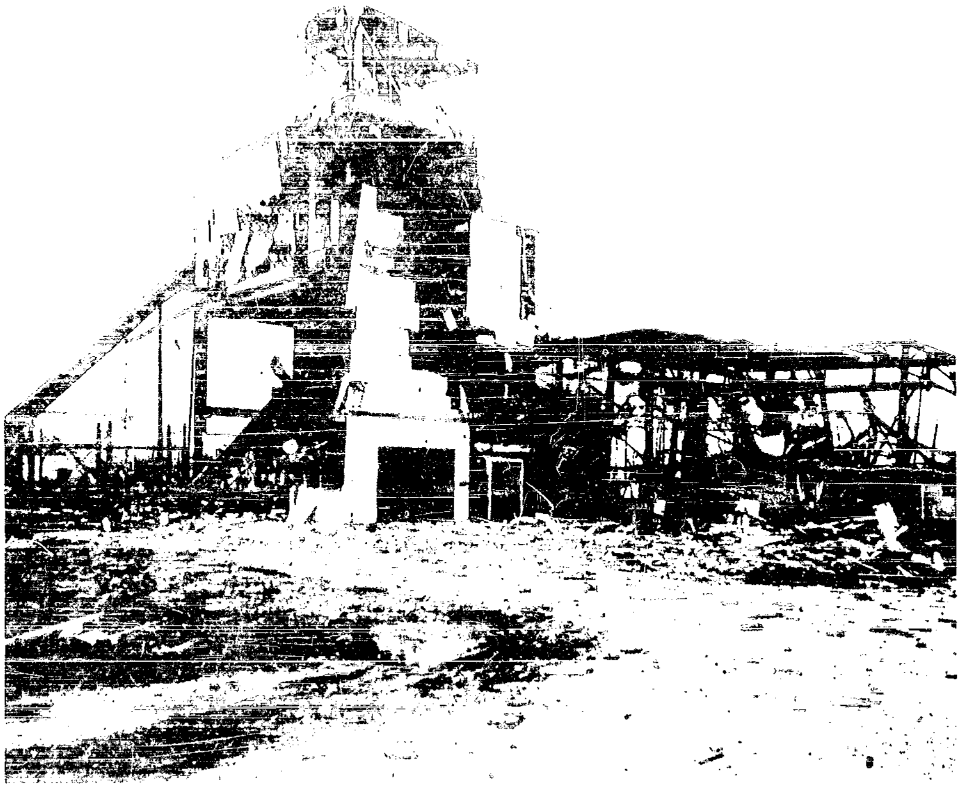
Slide 19

Thix mixer building was within two weeks of making explosives history. One day a mixer in this building caught fire three minutes after start up. This picture was taken right after that fire. The mixer was loaded with 1900 pounds of propellant and was operating on the reverse-mix method - meaning - the fuel was added to the full charge of oxidizer with the blades turning.



Slide 20

The fire resulted in this damage to equipment and facilities. There were three minor injuries to personnel who were operating the equipment by remote control within the building. Property damage amounted to more than $26,000. We believe that the fire was caused by a spatula in the mixer. This was only a fire. A detonation would probably have killed the three operators. Because of this fire, it was decided to provide a remote control station intraline distance from the building. All personnel were to be evacuated from the building during operation of the mixers. This was a life-saving decision, as it turned out.

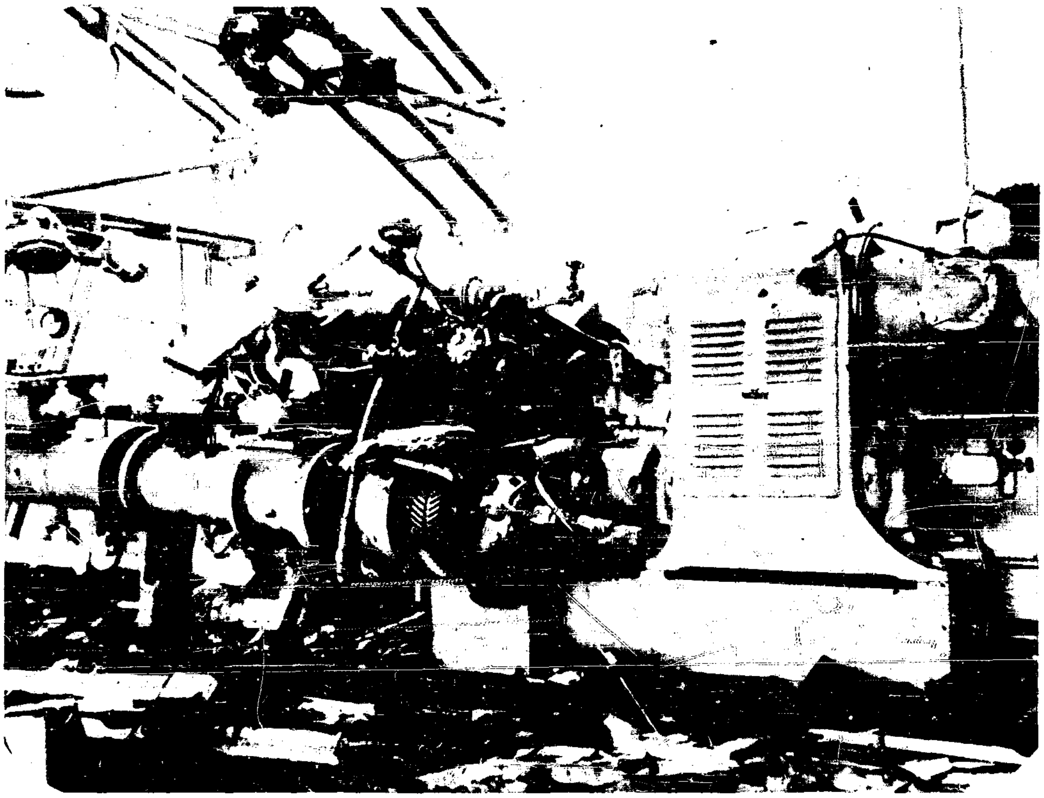


Slide 21

Here is the same location less than two weeks later. A 200-gallon mixer containing 1800 pounds of propellant exploded after one minute on the reverse-mix method in the same building. Property damage was estimated at $400,000. The building was a total loss. Missiles were located within a radius of 1000 feet. Half blades of the mixer were found as far as 625 feet away. Any personnel in the building would have surely been killed.

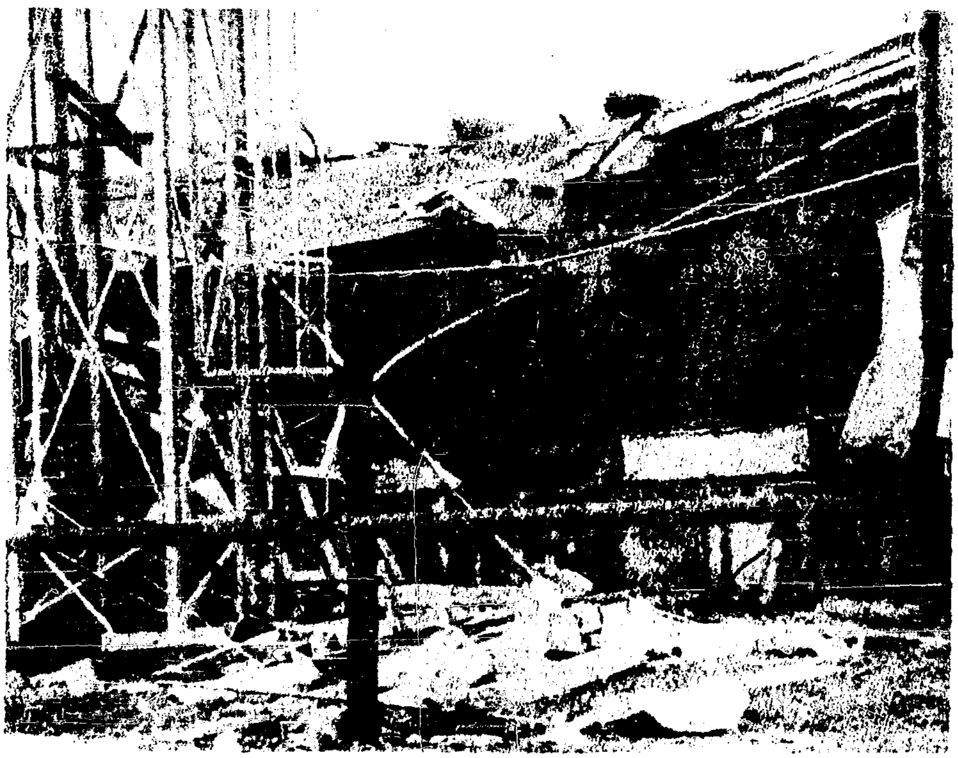
Slide 22

The mixer stood here. It is now a crater six feet deep, 12 feet long and seven feet wide.



Slide 24

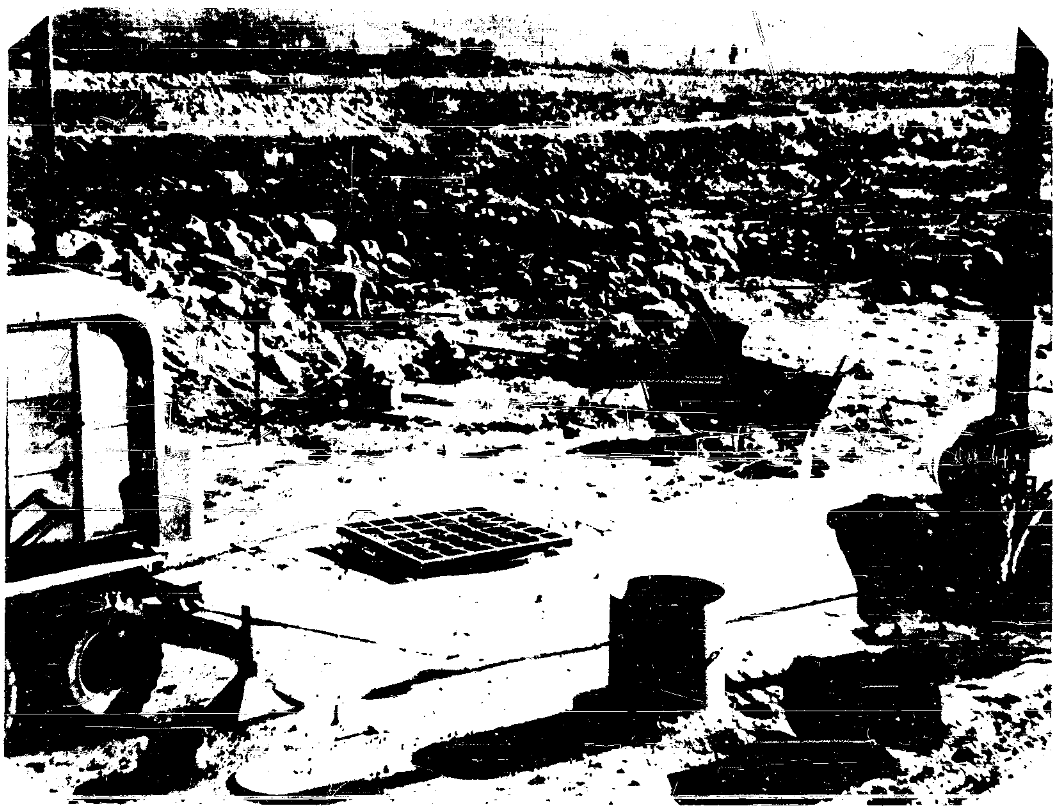
We also have had accidents involving continuous mixers. In this case, the liquid fuel mixture was being fed to the extruder automatically, and the oxidizer feed system was being controlled manually. The extruder had been in operation for ten minutes when the explosion of 30 or 35 pounds of propellant occurred. There was no subsequent fire. Frictional heat was the probable cause.



Slide 25

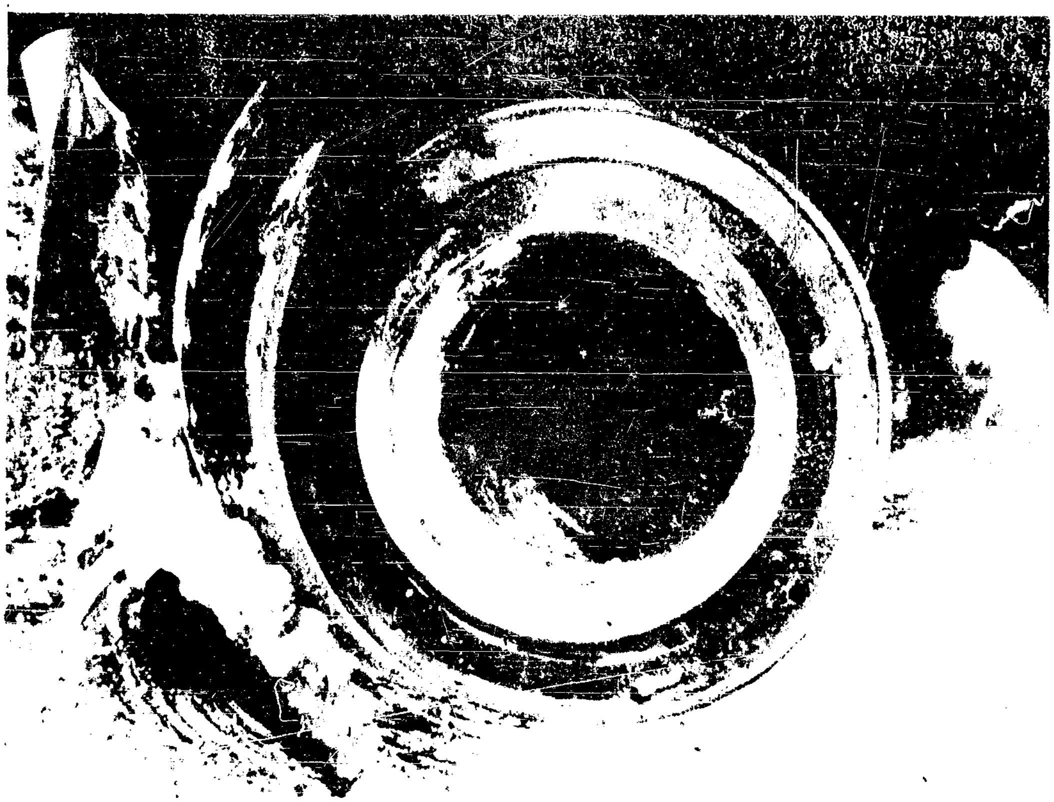
It will cost the Government $57,000 to replace the equipment and facilities. As indicated here, it doesn't take a lot of propellant to do a lot of damage.

Last year, the solid propellant industry suffered a tragic accident during the hand trimming of a large motor in a curing pit. There were three fatalities and property damage of $50,000. The trimming operation was conducted manually with a locally fabricated cutter assembly. No vacuum system was provided for the removal of chips and dust. There were no witnesses to the accident. Evidence indicated that ignition of the propellant was caused by the cutter assembly which permitted friction and pinching of the propellant.



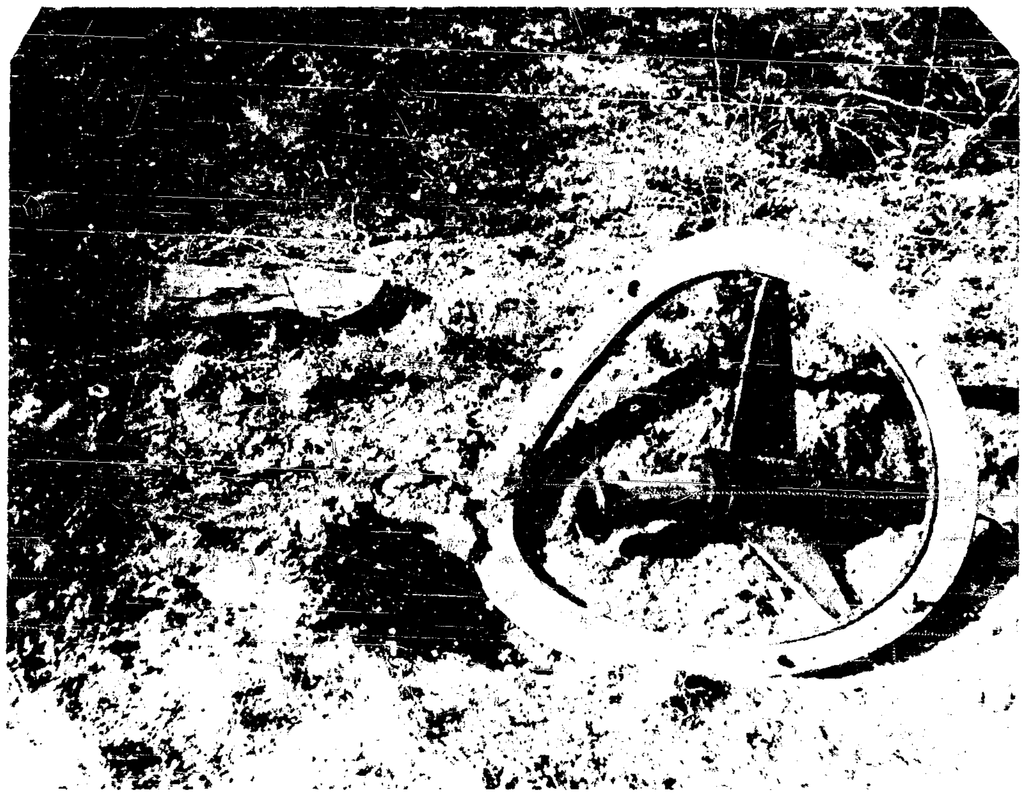
Slide 26

This is a view of the accident area. The curing pit is covered with a grate. The shroud containing the motor is at the right where it fell when projected from the pit. A crane for handling the motors is at the left. Personnel were blown 40 to 60 feet through the air.



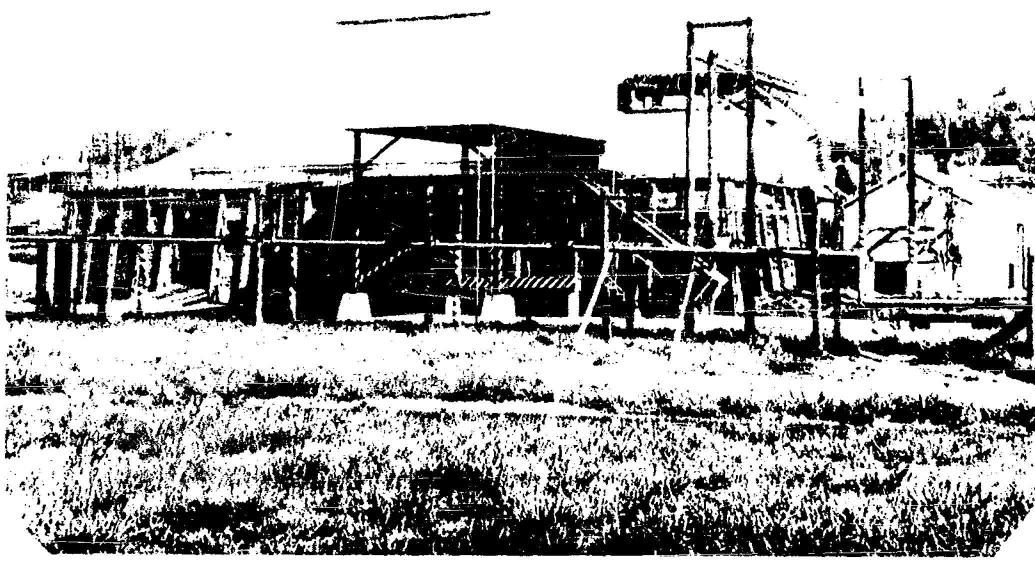
Slide 27

The nozzle end of the motor that was being trimmed at the time of the accident is shown in this picture. The motor contained 6900 pounds of propellant.



Slide 28

The propellant grain was trimmed with this cutter assembly. The plate containing the beryllium knife was sheared off in the accident and the assembly was projected 150 feet. It is ironic to note that drawings for a remote control trimming device had been approved just two weeks prior to the date of this accident. Time ran out for the installation involved. Equipment was outdated. Personnel were not protected.

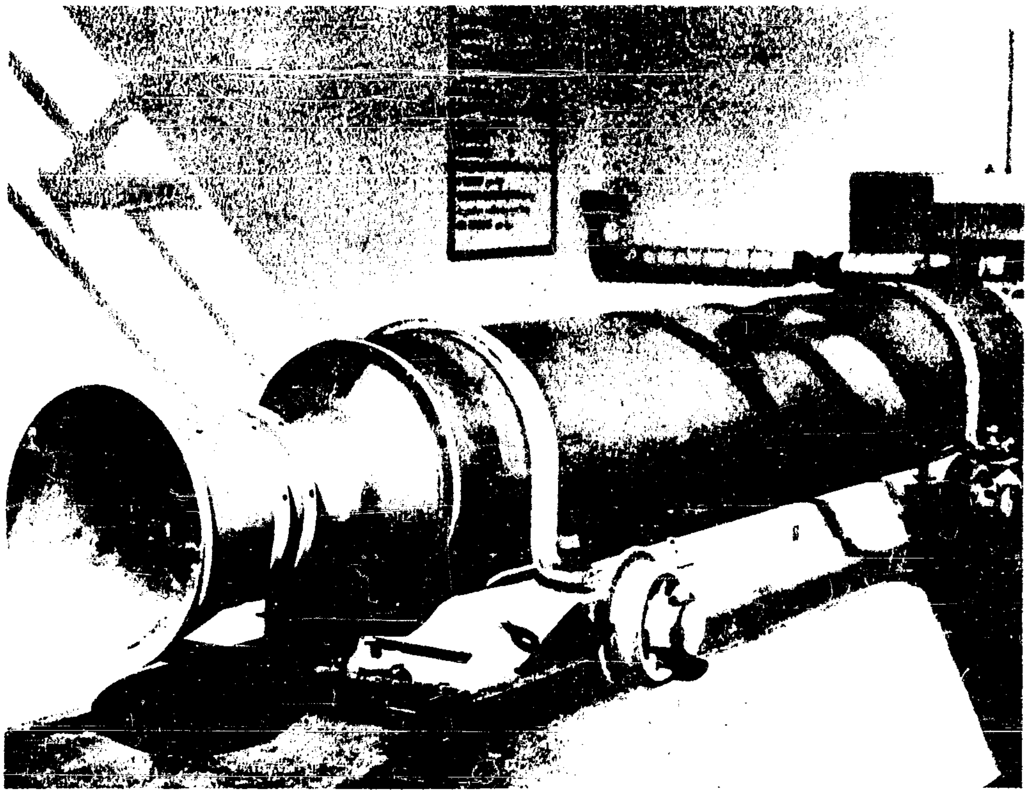


Slide 29

Here is a typical large grain curing house at an Army installation. It is not provided with a sprinkler system or lightning protection. During April of last year, a building like this burned to the ground. It had contained a total of 17 NIKE and HONEST JOHN grains - nearly 14,000 pounds of propellant.

Slide 30

The grains burned in place. There were no operations or personnel in the building at the time. Investigation indicated that the fire was caused by lighting. Cost - $225,000. Remember, it had no lightning protection. This costly fire points up the value of lightning protection and stresses it's need when the contests of a building have high strategic value. We can expect nothing else but total loss of building and propellant if a fire starts in this type of structure.



Slide 31

We have had trouble at static test stands, too. What man can predict that solid propellant guided missile and rocket motors will not explode when static tested. The Ordnance Corps has experienced a number of these costly accidents. Fortunately there have been no fatalities or serious injuries from them, but we have suffered heavy damage to test stands and the loss of valuable equipment. This R&D rocket motor loaded with 1900 pounds of cast double base propellant is ready for static firing.

UNCLASSIFIED

Slide 32

Instead of burning, however, it exploded. The 12" reinforced concrete wall separating the two test cells was cracked, and there was extensive damage to equipment and facilities. The property damage amounted to $50,000.

Slide 33

Several months later, another of these research and development motors exploded when static tested. The explosion occurred 35 milliseconds after ignition. Property damage in this one was estimated at $48,000.

Slide 34

Here is a test stand accident that surprised us. It occurred at the two-cell test stand shown here before the accident. Fifty persons worked in the electronics shop at the left. The shop and its parking lot is within 500 feet of the test stand. Personnel in the electronics shop are moved into a blockhouse approximately 300 feet from the test stand when large motors are static fired.

Slide 35

A R&D sustainer motor containing 6900 pounds of high-energy propellant detonated when static fired. The explosion occurred 50 milliseconds after ignition and resulted in complete destruction of the test stand and everything within a 100-foot radius. It made a crater 64 x 35 x 9½' deep. A concrete fragment weighing 5000 pounds was thrown 500 feet. Fortunately there were no injuries or fatalities. Only chance was the difference between life and death.

Slide 35

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Slide 36

This instrument van was parked approximately 400 feet from the test stand. A chunk of concrete weighing 2000 pounds struck the van, causing damage in excess of $100,000. A large number of private autos in a parking lot 600 feet distance were severely damaged by missiles. This explosion cost the Government over $500,000.

These accidents have been costly. We are exposing and losing too much of our equipment. It is evident that two-cell static test stands, and test stands that do not provide adequate venting in case of an explosion are inefficient and outdated. A serious delay in the test program could result if such accidents occur too frequently.

Static test stands and their operations must be engineered to provide positive protection to life and property, based on the maximum explosive potential of the largest missile, rocket or motor to be tested.

From what you have seen, it will pay to take another look at any static test stands you may have on your installation. Will they provide positive protection to life and property if a missile, rocket, or motor should explode in them ----------- today.

Many of you have heard it said that the Ordnance Safety Manual was written in blood. Now, this is after-the-fact safety. What we are striving for in the propellant industry is before-the-fact safety. Gentlemen, this is a must. We have had accidents, some serious ones, but we have profited from most of them. We in the Ordnance Corps make it a point to publicize our accidents. This is done to let other people - other installations - other services know what has occurred. By publicizing them, we try to prevent recurrences. It is one of the ways we can get value out of an accident. We make no attempt to criticize, or point the finger at the involved installation. We just don't want it to happen again - and neither do you.

To sum up what we've discussed, gentlemen, these are the points to remember:

1. Everyone involved with the manufacture and handling of high-energy solid propellants must exert every effort to search out all the hazards. One way to do this is to ask, "What would happen if ---------------?"

2. These hazards must be considered in our engineering. We must try first to "engineer" them out - eliminate them. If this is impossible, or unfeasible, then we must engineer the best possible guards against the hazards.

3. The employees involved in the processes must be trained - not just told - but trained to do the job the safe way.

4. Supervisors must rigidly enforce their instructions, and not permit deviations, short-cuts, or omissions.

It is my opinion that if all of us would follow these four rules, we would avoid many accidents that occur in the propellant industry. The accident pictures we saw should convince you that this is true.

If only one serious accident is avoided by some preventive measure or correction instituted as a result of your visit, this seminar will have more than repaid it's cost. The expense is a small price to pay considering the possible savings in life, property, and production. That one accident that is prevented may even affect our country's position in the world struggle!

Mr. Endsley: Do you have a breakdown on the dollar cost that you have had the past year on solid propellant energy losses?

Mr. Brinkley: We haven't broken it down as such. We keep a statistical summary of ordnance fires, but we haven't broken it down as high energy propellants or high explosives as such.

Mr. Endsley: Do you have statistics on the frequency of firing engines failures?

Mr. Brinkley: No. We keep statistical summaries. We keep dollar losses and fire losses on a continuous basis but we don't break it down into the category that you talk about. It can be worked out from our statistics. If you want this it can be worked out in several hours.

Mr. J. G. Thibodaux, NASA: I noticed that you referred to all of these as classified propellant formulations. I think it would be extremely important in the assessment of any of this information for everybody here to know specifically what these specific formulations were that caused the trouble.

Mr. Brinkley: That is one of the problems we have been fighting too for several years - to get information from private contractors and Government to disseminate this information. We have had a lot of explosions at one place and if we had known that other installations or other research laboratories were working with this material, these other accidents wouldn't have occurred. We have had in the last year two or three accidents, I'm quite sure would not have happened if we had accident information or that installation had had that accident information. I understand the Armed Services Explosives Safety Board is conducting some action on just what you have brought out. They realize the problem and they're trying to do something about it, trying to get contractors and people to disseminate that information because contractors are fighting for contracts and they don't want to disseminate that information. That is one of the biggest problems we have.

Dr. Karl F. Ockert, Rohm & Haas Co.: I would like to re-emphasize the point that Mr. Brinkley made about education of new employees. As you know the game of musical chairs is a very active one in our business, consequently we have a lot of new people coming in. I don't think anyone would argue the fact that the most unsafe time of our lives is when we are in college and it is doubly important then that new people coming in be properly oriented with an appreciation of the hazards they are facing. One of the most gratifying features about this is the fact that if you take the trouble to train these new people they themselves are very grateful and will take on this attitude with the world, they will be cautious if you start them off on the right track.

Mr. Fred Bishoff, OCO, D/Army: This is a partial answer to Mr. Thibodaux's question. The Army Ordnance Corps has a very extensive distribution list for accident abstract reports. For this reason the information as to the content of the classified explosives is necessarily omitted. If the operation is of interest to you and you wish to know what the material was, all you have to do is send a letter to the Safety Branch, Office, Chief of Ordnance, and we will in turn either advise you as to the content or give you the name of the installation or private company and you may correspond directly with them.

Col. Hamilton: Thank you Mr. Bishoff.

Mr. Charles R. Lowrey, Minnesota Mining Co.: We have had a number of incidents in our ARPA contract with pouring compounds and we don't publicize these very widely primarily because we don't have any mechanism for doing it that I know of throughout the industry and especially the installations doing research in this area. Is there such an organization now in existence that would publicize these incidents and if so how would we get in touch with this organization?

Mr. Bishoff: If you are operating under a Government contract, I would suggest that you notify the Army, Navy or Air Force, whoever is administering the contract and let them publicize the event. If you're not operating under such a contract, I would suggest that you correspond with the Armed Services Explosives Safety Board, whom I'm sure would publicize the incident.

Col. Hamilton: We would be very happy to do this at the ASESB.

Mr. W. J. Higgins, Rocket Power, Inc.: I was interested in basically the same information as has been requested. However, in our safety program at our facility we have a very large dining area for our propellant processing people and we have a large screen similar to the one in this room on which we project every type of safety film that comes along. I would personally like to have a set of these slides if it is possible to get them with a little literature to describe just what happened during the accident because we're in basically the same operation.

Mr. Brinkley: Request through channels and we will take action on it accordingly. Some of this material is classified, but the pictures weren't.

Col. R. H. Peter, ORDSO, D/Army: If you will send the request to me in writing, we'll see that he gets the slides that Mr. Brinkley presented at this meeting.

Dr. O. H. Johnson, BuWeps, D/Navy: There have been two items raised here that need some comment. My impression is that the research

laboratories engaged in solid propellant research in the early stages of development are not adequately covered by dissemination of information on accidents. Those of us that monitor these contracts are aware of the accidents and we disseminate them by word of mouth but that isn't adequate. These people are dealing with chemicals that the propellant industry has never seen, has no knowledge of, is unfamiliar with their properties and they're dealing with them every day. The comment of Minnesota Mining is an example of that. This is one of our contracts. I can name three or four contractors that are averaging from one to three explosions a week in the laboratory. Nobody is getting hurt, they are being careful, but these accidents are not being disseminated. We have attempted to make arrangements to disseminate detailed information on these - they are all classified - through the Solid Propellant Information Agency. We have run into a stone wall on legal implications. Many of the companies do not want their accidents disseminated this way. They don't want themselves named, they don't want the chemicals named, they don't want the people named, etc. There are a lot of legal complications here. If anyone can suggest a mechanism by which SPIA could put these things out in abstracts, we would be more than anxious to see that they are put out by SPIA. This can be done, we monitor that too. The next thing I would like to comment on, is in this R&D work in solid propellants which is not adequately monitored and there is no information exchanged now particularly on it, the chemistry is new to the propellant industry and most of the big motor companies unless they happen to have one of these contracts, are not too familiar with the work until after it has been underway awhile. Many of the companies doing this work are new to the propellant game. There is a real problem of indoctrinating and teaching these people how to work with these new materials. Some of them have gotten hurt. We had a fatal accident in one of our companies awhile back, an outfit that was fairly good in chemistry but was not trained in high energy chemicals safety practices. This is a real problem. This not only goes for the technical people themselves, but it goes for the safety officers. I've seen safety officers in chemical companies that the Government does business with that can not calculate for you what the blast pressure would be with a given amount of material. They have no idea what type of wall it would take to stop it and things like that. Such a safety officer is not a good safety officer to have around but I've seen them. I was visiting a large test firing cell just last week at one of our fairly large outfits. It's a brand new one, it's hardly been used very much. It is designed for firing 15 pound motors and it has a picture window, the only way I can describe it, going from the instrument stand into the firing cell. It's bulletproof glass but it isn't very thick and one pound would go right thru that window. They're planning to fire 15 pound motors in it. The people that designed that just have no background in this sort of thing. This is a problem - we're getting outfits into this propellant business that don't know it and there doesn't seem to be any good way to train

them in it. It goes not only for the technical people and I heartily indorse Mr. Brinkley's remarks on that, but also the safety officers of those same plants. But if any way can be found to use the SPIA abstracts to disseminate this accident information we'd like to do it, but there are a lot of legal complications.

Col. Hamilton: Thank you very much. I'd like to make one additional suggestion in connection with this dissemination of information. Most of you are working on contracts from one or other of the Services. If when you have an accident, for example, if you are working for the Army, if you would send a report in to the Army's Safety Office, they would inform interested parties, and if they come into possession of information which would be useful to you, I'm quite sure that they would pass it on to you.

Mr. L. J. Ullian, AFMTC, Cape Canaveral: I'd like to re-emphasize what the speaker said. At the Cape we have had many instances of accidents occurring, various pieces of ordnance firing, and after they fired down there for supposedly an unknown reason, the company of manufacture comes in and says we have had ten or 12 incidents very similar to this. In fact, last year the only man that was ever killed at the Cape was the direct result of an accident involving a missile, was killed in an incident that had occurred twice within two months before at the company's factory and yet they had not seen fit to inform anyone in the Government agencies that were using these devices. One man was killed and five others were injured. I might add that this company lost that particular contract as a result of this. We're not in the Government out to hang anybody in industry when they have incidents, but please tell us about them so that we can take adequate precautions if it happens to be a device that is sensitive or if there is a circuit that makes a device sensitive.

Col. Hamilton: Thank you Mr. Ullian.

Mr. Ernest Lovens, American Potash & Chemical Corp.: I have two brief comments I would like to make. One is that the Manufacturing Chemists Association has apparently solved the legal implications of reporting accidents by issuing regularly accident case histories in which the name of the company involved is omitted but the details of the accident, the cause and the corrective action taken is regularly reported and this sort of thing could probably be done and I certainly concur that it is a great necessity for those of us who have these responsibilities to know about what has been going on, so that we may better prevent this sort of thing in our own facilities. The second problem relates to the training of safety officers and personnel in the handling of explosive materials. I don't think we're going to do an adequate job as long as the situation continues that safety personnel have to be trained by a sort of apprentice system. I have thought very hard to

find some means of explosive training other than by learning it by word of mouth from a variety of people and also finding information which is now scattered through hundreds of documents in military publications which are not readily available. I certainly hope that some way can be found to correct the situation.

Col. Hamilton: The subject of safety training is going to be taken up later on the agenda by Col. Peter.

Mr. Endsley: This seems to be a tremendously important subject and we have got piecemeal answers. I would like to introduce a suggestion that a committee be formed to convene during breaks and after hours to study this problem and report back before we conclude the seminar. Because the free exchange of information and accident prevention is of such tremendous importance that I think it might merit a little night work.

Col. Hamilton: Would you like to name a place where they can get together with you so they can gather with you at that point?

Mr. Endsley: I think the Service representative can make selections from the various Services and organizations that might work on this.

Col. Hamilton: If necessary we can make an announcement later on.

Mr. L. Jezek, OCO, D/Army: With a few exceptions, I think that every one of the accidents that Mr. Brinkley has showed you on this board were publicized in our accident abstract reports. Now these reports were made available to the Army, Navy, Air Force, Coast Guard, many of our college laboratories, and any of you men that have contracts with Army Ordnance, if you will go to the Ordnance District office and just make a request that you want the reports that were publicized at this seminar, I'm quite sure that we can make them available for you. Where the information was classified, I think we make it a point to tell you that it was a classified item and as Mr. Bishoff pointed out, if you will direct your inquiry to the Safety Office in Washington and you are cleared for that information, I'm sure that we can make it available to you.

Col. Hamilton: Thank you Mr. Jezek.

Col. E. S. Howarth, DIG/S, Norton AFB: I think I have a suggestion for the committee. If the Explosives Safety Board would act as a clearing house they could collect this classified information from cleared industrial facilities. I presume that all of the facilities do have DOD security clearances. If this is the case then they could forward their classified information to the Explosives Safety Board who in turn could turn it over to ASTIA, the Armed Services Technical Information

Agency who's prime purpose in life is to feed classified technical information to U. S. industry. Through this channel other cleared DOD contractors could get the information. From the standpoint of the other DOD agencies, their input could be to the ASESB who in turn could send material back that came from any of the other two services.

Col. Hamilton: We have some accident summaries that will be distributed after this meeting. We prepare these summaries from time to time and they are based primarily on input received through the various services.

Dr. Ockert: We are missing the most direct way of communicating these accidents particularly in the solid propellant area. The gentleman from the Navy touched upon it, but you'll notice that all the routes that have been suggested to us always transfer the information from a contractor through some military channel and up and over and back down again. This takes time and the final recipient has to know what it is he wants to ask for. Now there already exists under the SPIA aegis a document which is called the JANAF mailing list. This is the joint Army-Navy-Air Force mailing list for the exchange of technical information. What it gives you is blanket authority for the direct transmittal from one agency to another without any intervening authorizing office or anything else. It gives you authorization for direct transmittal of all information up through the Confidential level. Now in answer to the gentleman from Minnesota Mining, I know that you are on this list and you can disseminate your report by letter to everybody else on that list. The Rohm & Haas practice is to issue a letter report within a week and it is sent to everybody on the JANAF list, about 150 installations. Since we all have security clearance here, it is inconceivable that there are very many of you who do not have rights under this JANAF mailing list. This allows for direct and prompt information exchange of these incidents if the people who have the accidents will be conscientious in reporting them.

Lt. Col. Gerald Couch, USAF, ASESB: Is there any representative of a contractor or operating agency here who would not be willing to report such incidents to an activity set up to distribute and disseminate the information? One of the problems that we know of is that some contractors do not wish to report such incidents. Are there any here that would not report such incidents? Since no hands have been shown, I assume then that everyone would be willing to report such incidents.

Mr. Lowrey: We think that it would be real good to use the SPIA list as Dr. Ockert suggests, however, to do it on the basis of every incident is difficult. Because I know that in the past month - I'm a research chemist working in a laboratory - I alone have had at least four incidents where by taking safety precautions we haven't had anyone injured but have destroyed equipment and my incidents were just one of the activities of a group of maybe another ten people that are all

having these same incidents with more or less frequency. So to send out a letter every time you have an incident is impractical. We just can't do it. If you do it on the basis of a time interval, this is feasible. We have reports incidentally that we make out on the basis of each incident which describes the incident, describes the safety procedures that were being taken before the incident, what modifications in the safety procedure are recommended and subsequent action is generally allowed for on this form so that any safety engineer that wants to check into it in a week's period of time can see that these safety changes have been made. I would like to suggest that if we do this, have lists of these incidents circulated to all the people on the SPIA list, that we do it on a time basis, rather than on a frequency basis because it's just too expensive to send out an agenda for each incident that occurs.

Col. Hamilton: I think the subject can be explored much further when the committee suggested by Mr. Endsley is formed. Our next speaker will be Dr. E. C. Noonan, the subject 'Advances in Sensitivity Testing.'

Dr. E. C. Noonan, NOL, White Oak, Md.: Col. Hamilton, gentlemen of the seminar, I'm very happy to be back here again this year. This is another episode of the soap opera of my love affair with the gap test. I remember Lawyer Miller from last year and I remember a good many of the others. And I also know exactly where I am. I'm the 365th man on the moon, it's only a little ways outside of Los Angeles but the daytime temperatures are exactly what they were said to be. Now I'd like to show you some slides.

The first slide is our configuration we used for the gap test, the screwey numbers are there because we measure the thing in inches and then we put them on slides in centimeters. But there are a couple of things I want to point out on this again. We have a couple of tetryl pellets each an inch thick and 2" in diameter that provide the initiation boost pressure. They go to a stack of cards each one of which is 1/100th of an inch thick or an equivalent column of lucite into the acceptor propellant which is in a case about $1\frac{1}{2}$" inside dia., 1.437 to be exact, $5\frac{1}{2}$" long. The witness plate is about 4" across. The point up here is what I'd like to show you. There is a little air gap there and that was designed into the experiment originally for two reasons. One is that we wanted to be sure that when we conditioned these propellant samples at low temperature and high temperature and placed the plate on it wouldn't transfer a lot of heat. And the second reason it was put there was to prevent a shock initiation at the plate because of shock reflection. You can get a much higher pressure when the wave enters the plate. I'll talk about this a little later. As a result you might get an initiation there. So we consider this area at the top rather important in this thing. Dr. Price of our Laboratory did quite an extensive examination of the criteria of detonation in the gap test.

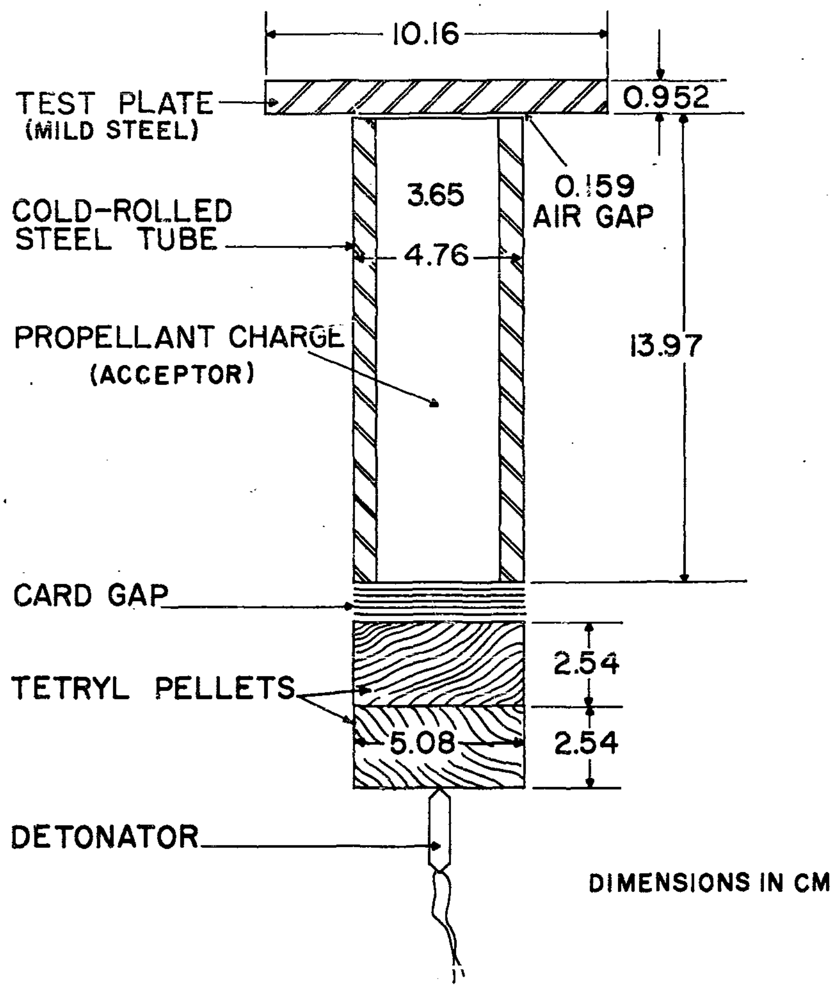


FIG. I CHARGE ASSEMBLY AND DIMENSIONS FOR NOL GAP TEST

This was published in the May issue of the American Rocket Society Journal to try to disseminate what we get very rapidly. The criteria that we have chosen now is a hole punched in the plate. This witness plate is just lying on top of this assembly. There's nothing securing it, nothing holding it down, just inertia that keeps it there when the hole is blown. Prior to this time we had observed these in which the plate bulged or had bumps in it and we considered this an evidence of energy release. Dr. Price made a very careful examination of this and decided that there was only one criterion we could possibly use and that was a clean hole punched in the plate. The reasoning goes this way. Last year we calibrated the gap test in the sense that we determined the pressure in this column of gap material as the function of the distance. Of course this pressure gets attenuated as it goes down the column.

The next slide shows the calibration. (Omission due to poor recording.) You get 60 kilobars 10 or 15mm out from this thing. As you go further out it is down to about 10 kilobars at about 90mm away or a little over 3". If you plot this on a logarithmic scale, I don't have a slide showing this, but if you plot on a logarithmic scale you get a very nice straight line and you can fit it to an exponential type of decay equation which is very good after you travel the first 20mm or so. The pressures actually appear to fall away a little lower than the logarithmic curve but everything from there on is still rhythmic. When you transmit the pressure from this lucite into a material with a different acoustic impedence, a different density and in sound speed, the transmission is not perfect, you get some reflection and some of it goes through and the degree of mismatch and impedence determines how much goes one way or the other. So Dr. Price and Mr. Jaffe performed the following experiment. Instead of putting that acceptor material, i.e., the $5\frac{1}{2}$" tube which is $1\frac{1}{2}$" in diameter filled with propellant in between the lucite and the witness plate, they laid the witness plate directly on the lucite and they kept varying the length of this column until they found the point at which the plate was punched 50% of the time. They found that this column where the plate was punched 50% of the time was about an inch long, or about 254mm. This meant that the pressure was somewhere around 43 kilobars in the lucite column to just punch the hole in the steel plate. Then they applied the properties of these solids to find what the pressure was at the interface between the steel plate and the lucite column.

The next slide shows the method of getting at this. I won't go into details of the mathematics of it but this is the way you get at it. You remember the pressure was 43 kilobars at the end of the lucite column. This represents point A here. What we've done is to plot the pressure vs the particle velocity in two

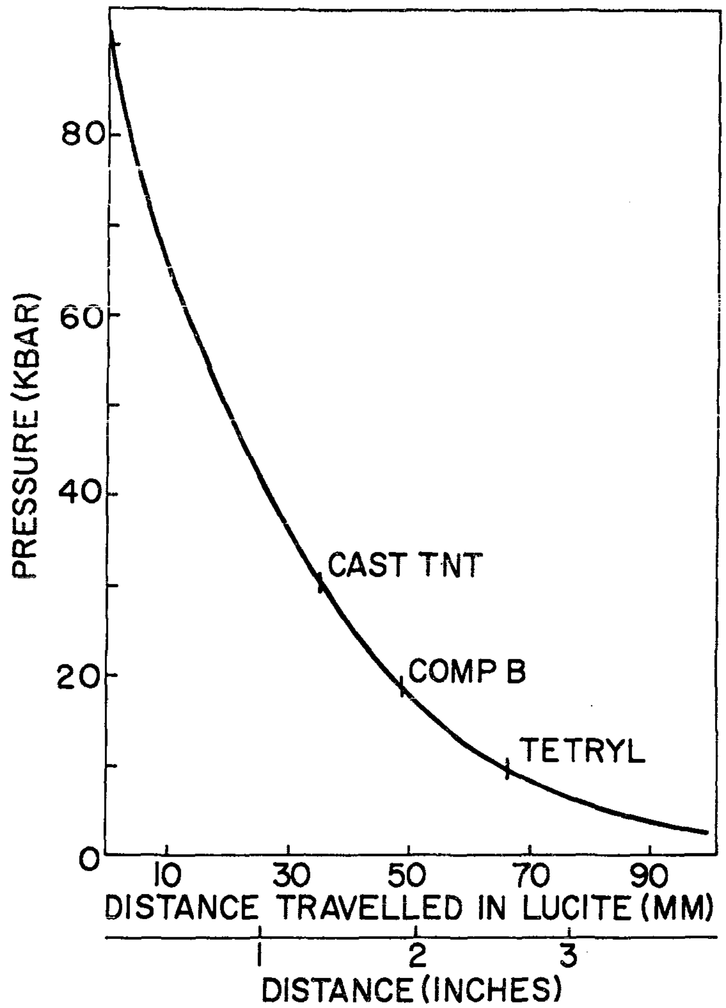
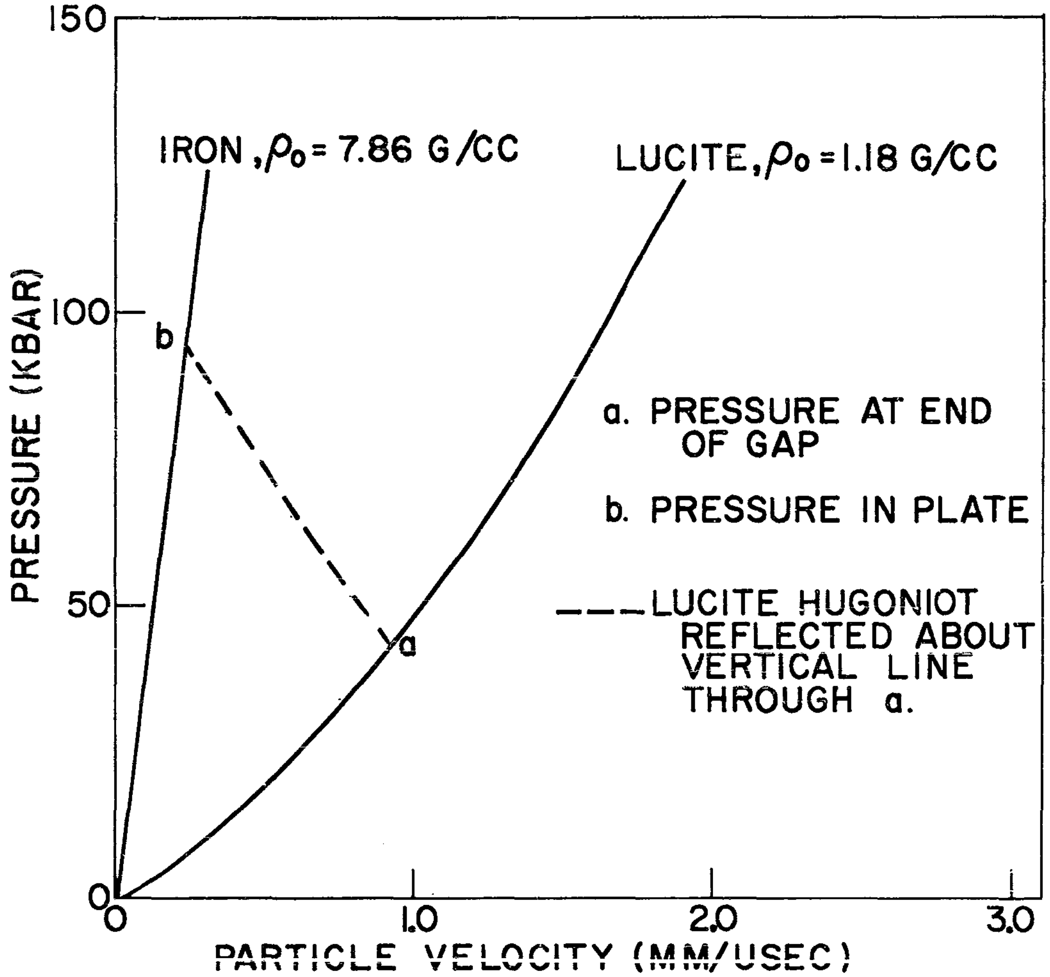


FIG. 2 CALIBRATION CURVE FOR GAP TEST


150
100
50
0
PRESSURE (KBAR)
IRON, ρ_0 = 7.86 G/CC
LUCITE, ρ_0 = 1.18 G/CC
b
a
a. PRESSURE AT END OF GAP
b. PRESSURE IN PLATE
LUCITE HUGONIOT REFLECTED ABOUT VERTICAL LINE THROUGH a.
0
1.0
2.0
3.0
PARTICLE VELOCITY (MM/USEC)

Slide 3

different materials, iron and lucite. These are the so-called "Hugoniot adiabats" and at the interface between the lucite and the witness plate, the pressures across the interface must be equal in order to conserve momentum and energy. So knowing this and knowing that the pressure at the end of the lucite would have been 43 kilobars if you are transmitting in to more lucite you take the curve which is the "adiabat" for lucite pressure in kilobars vs particle velocity in the material in mm per microsecond and you simply reflect it around a verticle line running through A. Where this curve intersects the iron curve gives us the pressure at the interface of this thing and this works out to be about 94 kilobars. In order to punch this witness plate which is 3/8ths of an inch thick you need a 94 kilobar pressure. This tells us that our criteria has some limitations in it. TNT going at full detonation velocity, full detonation pressure would reach a pressure of about 58 kilobars. Again in order to compute what the pressure is at the interface, you have to know a similar "Hugoniot adiabat" for TNT which would fall along somewhere in here. The literature doesn't have very much of this in it, fortunately the Russians in recent weeks have published some information on unreacted TNT, i.e., the pressure corresponding to particle velocity in the shock wave and unreacted TNT. From this you can find the pressure necessary in TNT, if you are using this to punch a hole in the plate should be something like 58 kilobars. TNT at a density of unity produces a pressure of 64 kilobars, so that TNT very clearly punches a hole in the plate. On the other hand there are certain explosives even if they go at full pressure and full velocity, will not punch a hole. Dr. Price thinks ammonium perchlorate, for example, is one of this type. Usually or very often the detonation velocity and detonation pressure go hand in hand, but I hasten to add that this is no guarantee that they always do. Nitroguanidine is an exception and it's the pressure that does the punching, not the velocity in spite of information to the contrary that's crept into the literature. So that one has to have a pressure in the explosive and this varies a little bit with this "Hugoniot adiabat" of explosive of around 54 kilobars in order to punch a hole in this iron plate. If you have less than that it won't punch it. Previously we observed that when the velocity of the explosive was about 5,000 meters a second, which is about the velocity of sound in steel, you didn't get a good clean hole in the plate, you got a dent. This clears things up very nicely. You have to have a pressure of around 54 kilobars in the explosive, it has to produce that detonation pressure in order to punch a hole. Some of the things that we have been calling energy releases then may be full order detonations. There are very few exposed propellants that show this kind of thing but we need to know this so we are in the process of calibrating some thinner plates in order to determine or learn something about explosives which have lower detonation pressures than the ones that we commonly deal

with. Of particular importance to this are the commercial explosives and nitramons, dynamites, things of this type which we'd also like to classify on the gap test. When we tried to calibrate thinner plates, we got real scientific about it and we annealed the plates. Previously we had just been using cold rolled steel plate, cut it off into 4" lengths. So we very carefully got a nice lot of steel we know all about. We annealed the plates very carefully. It didn't produce a clean hole and our nice clean end point for the gap test went all to pieces. So we have to go back now with different materials or go back to cold rolled plates so that we can calibrate this test for lower pressure explosives. And we are in the process of doing this now. We do have a good criterion now for a go or no-go in this test. There's another point in which there is an impedence mismatch in this gap test and that is the point where the shock wave from the tetryl pellets that have gone through the donor enters the explosive. And if the "Hugoniot adiabats" were for lucite and for the propellant materials that do not match, then you get again a difference in the amount of energy transmitted, some that gets reflected back and the pressure may be higher at the interface than the pressure you would calculate from the end of your lucite column. Dr. Price went through this very carefully and she found that as best she could estimate what these "Hugoniot adiabats" are on unreacted propellant - again unfortunately there's not very much in the literature about this. She found there are no unexpected reversals or anything of that sort and there was a pretty definite relationship between them. The next slide gives a quick look at the relationships she found.

Actually the pressure at this point appears a little bit lower - 20 kilobars - than the pressure at the end of the lucite charge because the impedence mismatch happens to be in that direction. Impedence is worked out; rather, acoustic impedance is now the product of the sound speed by the density of the material under consideration. From this she was able to compare the results of the pressure applied in the gap test to pressure that was applied if a bullet hit the thing. Whitbread, Steel, and Brown in England measured sensitivities of a bunch of explosive by projecting a cylindrical bullet at the explosive and the bullet had a soft end on it. This impacting cylinder produced a pressure which initiated the explosive. What she was interested in was how the pressure developed in this test compared to the one on gap tests and she found they were identical when you took this impedance mismatch correction into account. Right away we can do something. We have learned how to correlate this test, the gap test now, with the bullet test, for detonability at least, not for flammability, but for detonability. Whitbread also found out that if you use spheres, ball bearings for missiles instead of flat cylinders, the velocity that you needed to make a sphere initiate the explosives was much

higher than if you used the flat faced cylindrical bullet. In other words, the cylindrical bullet was the worst case. Then the sphere required a higher energy than that and I am told that an ogive type bullet would require as much as a sphere if not more and that a jogged fragment would require about the same energy. So you have now a way of classifying the explosives in terms of bullet impact. You can take this worst case which is the flat faced cylinder and compare it with the gap test and since we accurately know now what the pressures developed in the gap test are accurate to at least 5% or 10%, we can have a very clear route as to how to specify what gap test value the material must have in order to keep it from detonating if it's hit by a bullet. Here's the route. First of all we have to decide what velocity is our fragment going to have. We can assume it is steel, because most of the fragments we deal with are going to be steel and this will be the worst kind of fragment that you can get, short of uranium or platinum or something like that. But we'll assume the fragment is steel. Then we have to decide what velocity can it possibly achieve. Well, the muzzle velocity of guns, the old-fashioned type of 1950 (I'm talking about big guns now) varied from around 2,000 to 3,000 feet per second. The fragments from explosives loaded items; that is, we have a case loaded with explosive and detonated, it's very hard to get velocities much over the particle velocity in the explosive, so that you can say somewhere around 4,000 meters per second is going to be about a top limit from a practical point of view. So let's pick an area around 10,000 ft. per sec. as the maximum fragment velocity that we have. The only other thing that we need to know here is the "Hugoniot adiabat" of the explosive under question. This is not going to vary over a very wide range. You can calculate the pressure quite simply from the relationship that the pressure is equal to the velocity of the thing hitting times the density in the sound velocity in the thing struck. So that you can get a pretty good motion of what card value you have to have in order to prevent the thing from detonating. I haven't actually calculated this but you certainly can do it and as far as I'm concerned this can completely replace the bullet test; the gap test can replace the bullet test and the bullet test is obsolete for detonability. Now it doesn't tell you a thing about flammability and if there's anyone here that insists on us doing full scale tests on this, even if you are an engineer and you have to believe in science, pick some scientific flaws in this but please don't do these full scale correlation tests. You may do one and you may get a detonation, but if you do the next thousand you won't. I'm pretty sure of myself on that. To give you some idea on the meaning of this gap test in terms of practice, I'm going to utilize a little material that was acquired at Dahlgren recently.

This film was taken by Mr. Kasdorf's group and shows the effect of high velocity impact of nitrosol explosives going thru barriers. The barrier may have been a 12½" reinforced concrete wall or it may have been an inch and a quarter steel plate. The method of doing this was to load the propellant into a Bullpup warhead, about 104 pounds of propellant in these warheads, and then they were attached to a rocket sled and accelerated down a track, until they reached a velocity of approximately 1,000 ft. per sec. They varied between 940 and 970 ft. per sec. The sled parts were then swept off by passing this warhead through holes in tremendous steel plates and the warhead went on and impacted the target, and went through it. This particular nitrosol propellant is not a propellant. It has been reformulated as an explosive. We're interested in it for underwater explosions. This particular one has a card gap value of about 74 cards as .74" of lucite will stop the detonation 50% of the time. Which means that it is somewhat less sensitive than TNT. On the impact machine this material has a sensitivity of 14 centimeters with a standard Bruceton machine with sandpaper on the tools and 23 centimeters with bare tools. This makes it an extremely sensitive explosive. According to that test - of the order of magnitude of PETN - you can see that this impact test is far more drastic and that the gap test is a much better correlation of the test results that they obtained than the impact test. What happened was that none of the warheads that were impacted on these, passed through these concrete walls, or through the target plates blew up high order. There were a lot of ignitions, very active deflagrations, but none of them went high order. The film clips are not edited and they will show you a little bit of what happened. I'll try to explain them as we go along. Maybe Mr. Kasdorf can amplify later on. Here's the impact, you get a flash but it goes through. This was going through a concrete wall and you see the thing deflagrating afterwards. The next one shows it from the other side, this is the material burning up afterwards. It survived the impact. This material would probably not pass the 30 fram tetryl test. We proceeded in reliably detonating this material with 30 grams of CH6. On a weight for weight basis this is about equivalent to the tetryl boosters that we used. I think the 30 gram tetryl test is much too harsh. A velocity of 1000 ft. per sec. is about 700 miles an hour or Mach 1, so that if one rocket filled with this thing fell off a train going at Mach 1, it would probably deflagrate and not detonate. If you dropped it in a vacuum from a height of three miles, it would hit the ground and it wouldn't detonate. On the other hand, I don't think it would pass the 30 gram tetryl test which we're talking about as a hazard classification. So I think this is a pretty good example of the kind of thing that the gap test evaluates, initiation by pressure. Now what we really need is some other quantitative tests, one of them for ignitibility, the impact machine test very often shows this

but not quantitatively and it's almost impossible to analyze. If we have some good quantitative tests of ignitibility and I don't think the JANAF AdHoc ignitibility panels have yet come up with anything that can be reproduced anything like the extent that we can reproduce this one. Then this would be a very useful piece of information because this would assess this kind of hazard, the hazard of ignition. Then the next thing we need to know is the probability of transition and finally we have the shock sensitivity. The probability of transition, there isn't any one single test that is tied in to the fracture mechanics of the material to a very large extent. We had five lots of ten charges each of Comp. B explosive made up at different times in the casting house. We took these fifty charges and fired them in random order and determined the 50% point, found that the Comp. B was 201 cards plus or minus 1.6 cards. This means that the test is highly reproducible. In fact, what we found out from this was that we could reproduce the card value better than the casting house could reproduce the Comp. B. Although they were given minute instructions on casting it, it turned out that they deviated from this a little bit and some of the charges were cast into molds 5° hotter than the other. We could pick this up on the gap test. It's a very sensitive and accurate test. Another thing we investigated was the affect of confinement and again the material was the high explosive that we used. We used different case materials. Normally we use a steel case. Now lead, steel, aluminum, Comp. B, glass and lucite were employed as the confining materials in these instances. The net results are shown in the next slide where both the card value and the pressure required at the 50% point are shown. With Comp. B you have steel confinement that required 206 cards to get a detonation 50% of the time. At the 50% point pressure was 15.6 kilobars. Here are the results with lead, aluminum, Comp. B, glass and lucite. You see you get quite a bit higher pressure with lucite. If you had just air and here instead of having the charge diameter the same as the outside of our steel case, it was the same as the inside, it would require 30 kilobars. All these tests were on a constant wall thickness except the glass which was a little bit smaller. The effect of confinement you can look at several ways. It might be purely inertial. You figure out how much Comp. B would be required to replace the mass of a steel case and see what you would get, or glass, or aluminum, etc., or it may be a function of the acoustic impedance or some related factor such as a double transit time or it may depend, as some people have suggested, upon catalysis or chemical activity. Dr. Price, whose opinion I respect very highly, says this is "nuts" that nothing will have time to react in order to contribute, on the other hand, Dr. Jacobs whose opinion I respect very much says yes, the effect of the gases will be to scrub the surfaces and you'll get a lot of new surface and you will get chemical reactivity so this may make a difference and no matter how you analyze these things, some

SENSITIVITY OF COMP B VERSUS CONFINEMENT

Material	50% Point cards	50% Point Pressure kilobars
Steel	206	16.6
Lead	207	17.0
Aluminum	179	21.6
Comp B	159	26.0
Glass *	158	26.2
Lucite	156	26.7
None (air)	143	30.0

* All tests at constant wall thickness.
1.875" OD   1.437 I.D. except glass
1.750" OD   1.45 I.D.

Slide 4

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anomalies will show up. I think one Air Force contractor suggested that the electrical conductivity of the case was important and this stupified me slightly for awhile but it did lead me to plot up the price of the case materials vs the effects and I found the most expensive things were the least effective. It just illustrates how you can analyze the results but still get anomalies and this I won't own if it turns out to be wrong.

The next slide will show what I did. I assumed that it was purely inertia and I calculated what the equivalent diameter would be for a Comp. B charge of the same total mass. Then I assumed - this was purely an assumption now - that this would vary as a reciprocal of the charge diameters as the plotted reciprocal of charge diameter vs the pressure here. I have two cases in which there were bare charges, the bare charges were about 1.43" in dia., another one about 1.875". This conveniently gave me only two po n so then I could draw a straight line between two points and down here. There is a lot of give and take in this. Then I plotted up the other things on the thing, I calculated the equivalent diameter for steel. The same mass turned out to be 3.41" and fell down here. So it's about 100% effective and lead is about 72% effective and aluminum is 120%, glass seems to fall on both sides and is a little more effective. No matter how you do this and I did it several different ways with acoustic impedences and everything else, you get mix-ups every time. You don't get an unequivocal answer. I think it does show that confinement does do some good. We're essentially testing things of higher effective diameter than we would if we didn't have a case and we ought to stick with it if we're using a test although the fragment hazard that you get is undeniably a nuisance. In connection with some other experiments, we were interested in the shape of a detonation wave emerging from the tetryl booster pellets. It has been suggested by one group that we use conical booster charges instead of cylinders. One can look at the shape of the wave from the tetryl booster entering the lucite pellet by photographing that charge head on and the next slide shows how we do this.

It's not a new technique, it's an old one. We use a mask which has a series of holes punched in it radially and the charge is photographed head on through this mask with a smear camera and this is the slit of the smear camera. If you put a very thin piece of lucite, 3000th of an inch from the front of the charge, it shatters when the shock wave hits it and it keeps the light from the charge being rewritten on the record so that you get a record that you can read and there is a time delay from the center of the charge to the edge. The center of the charge lights up first and progresses toward the edge of the thing and from the

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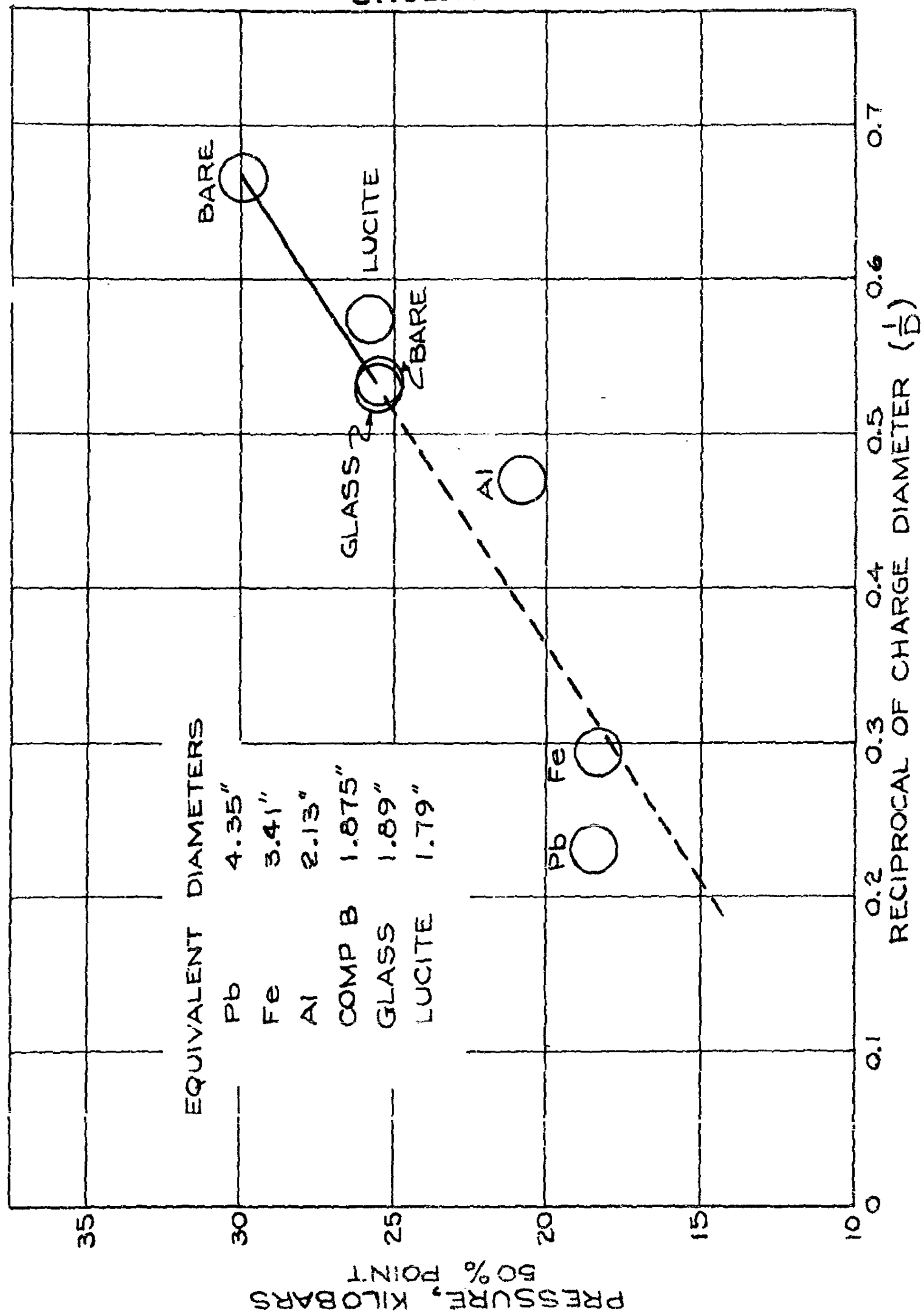

Slide 5

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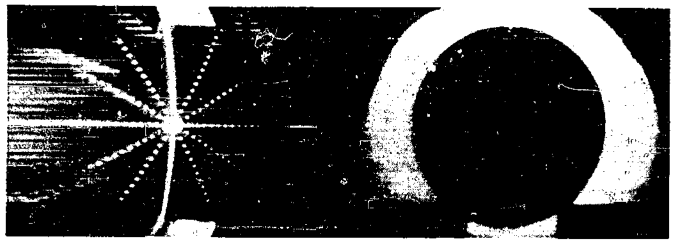
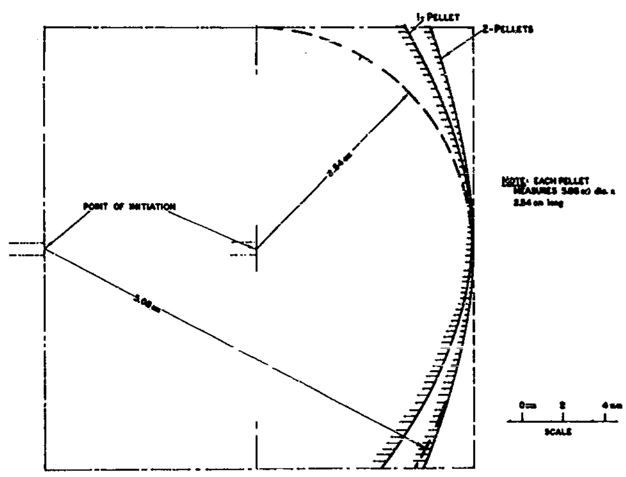


Slide 6



DETONATION PROFILES FOR 1 AND 2 TETRYL PELLETS

Slide 7

farthest point illuminated and knowing the velocity of the detonation, one can calculate the shape of the wave and the next slide shows what kind of a looking wave we've got. If we have a 1" thick tetryl pellet this thing is drawn to scale. I understand this is a little off over here, but this corresponds to 1" of tetryl pellet. If you got a spherical wave it would have this shape. The shape actually found from one pellet looked like this. You got a curved front of this configuration. If you have two pellets you should get a spherical curve that looks like this and you actually get one that is a little less curved than with the one pellet but not improved too much. Now going to a conical booster which would give you 3 to 1 length - in other words your point would be out here somewhere - wouldn't really improve the shape of the curve very much and so we really don't consider this necessary. It's a little more convenient physically I think to work with straight charges for small size material, not for the large so we'd prefer to stick with the cylindrical booster. And even in the infinite diameter you should get a curvature according to the curve front theories.

Col. Hamilton: Are there any questions that you would like to ask Dr. Noonan?

Dr. W. B. Gordon, Institute for Defense Analyses: What I'm concerned with is the situation where the explosive or the propellant that you are testing in the gap test is unable to propagate in the diameter of the test piece, that is where the test piece is below the critical diameter even in view of the confinement that you have?

Dr. Noonan: The answer of course is you don't get any propagation if it is below the critical diameter. It takes quite a lot of extra pressure if you're in the neighborhood of critical diameter. With TNT whose critical diameter is about 3/4" it takes 150 kilobars to initiate it. If its 1½" in diameter it takes 30, 1/5 as much so if you're very near the critical diameter you have to apply an awful lot of extra pressure and this is one area in which it is a little obscure, you know, fixing on a specific size test. The people at Rohm & Haas feel you should go to much larger sizes and they are right for materials which have critical diameters much larger than 1½". Some of the propellants can have this because they're heterogeneous, their reaction times are slow, the reaction zones are long.

Dr. Ockert: In conjunction with this minimum diameter problem I want to say in defense of the NOL tests and they do beautiful work there as you can see, that from the standpoint of practical propellants in the heavy confinement such as is used in the NOL test any reactive binder propellant that we can think of that we have looked at - and Rohm & Haas has looked at quite a number - would have a minimum diameter which is below the 1½" which is shown here. We have come across instances of certain propellant ingredients where the minimum diameter has been greater even in steel than that in the test. But from a standpoint of evaluation of propellants particularly since we're going into high energy propellants, I don't think that there is any serious practical handicap to the dimensions on this test as it stands.

Dr. Noonan: There's one serious handicap, it's too big. You're going to have to use too much material. There is a smaller one that has been used at NOL that is only ¼" in diameter and about 2" long. Mr. Ayers has recently calibrated this and done a pretty good job of it. Mr. Wenograd has even gone smaller, he does his in a hypodermic needle but it's only good for liquids.

Mr. L. W. Saffian, Picatinny Arsenal: Dr. Noonan, all these examples we've seen involve the contacting of a bare explosive as far as I could see. The contact was made in such a manner that whether it was a natural blast effect or pressure effect or whether it was an impacting missile, virtually the entire surface of the explosive was enveloped by the wave or hit by the fragment at the same time. Would you care

to comment on the applicability of this technique to a situation where: 1 - you have a cased material; i.e., the casing is around the surface that it impacted and 2 - the situation where you have a relatively small projectile piercing the casing and contacting the explosive?

Dr. Noonan: Yes Mr. Saffian, I will comment on both of those. First, the case acts the same way that a gap does, its an attenuator and the only thing you have to worry about is the acoustic impedence of this case as to what pressure you get when you load the outside. The pressure you get at the interface between the propellant under test and this is the thing you can get out of the gap test. As far as the difference between a loading over the whole surface, you have to do this in order to get reproducible results. This is the worst possible condition. Again Whitbread and Brown found that if they had a cylindrical flat-faced bullet and the flat face hit on the explosive it took a lower velocity to make it go than if you had a spherical bullet. If you have a fragment or you have an ogival bullet, it will take just as much more velocity, more energy to make it go. So I think the gap test gives the worst possible conditions. If you can't detonate it with a reasonable velocity of projectile flat-faced or with a reasonable pressure, then you can draw a line and say you can't detonate it with any fragment whose velocity you would ordinarily measure. What do you think is the highest limit for a fragment velocity?

Mr. Saffian: I agree with your upper limit which was 4000 metres per second. I think this is a practical upper limit. What I was referring specifically to here was the fact that in the case where you get a penetration, there are heat effects; for example, in tests that we've run we've actually melted fragments and fuzed casing materials.

Dr. Noonan: I was very careful to state this measured only the detonability, not the inflammability.

Mr. Saffian: No, I mean detonations which are induced partially at least by heat effects.

Dr. Noonan: If you do that you should be able to do it with the gap test also I think.

Col. Hamilton: Thank you very much Dr. Noonan. The next subject is the 'Development of Criteria for Assessing the Thermal Stability of Propellants other than Nitrate Ester Bases', Mr. Visnov of Frankford Arsenal.

Mr. M. Visnov, Frankford Arsenal: At the very beginning I'd like to clarify one point. Your agenda states 'Development of' and at the outset I want to put in a slight hedge. Precious little has been developed. My purpose in these remarks I make here is to crystallize

a little gap in our propellant knowledge and perhaps some thinking along these lines. I want to present this problem and clearly understand that it has not been solved as of today and I would welcome anything from anyone who feels that he may have. In order to do it, I would like to present a picture to you. Those of you who have been in the solid propellant field for some time know that if you go out into the field and get a piece of propellant loaded hardware where this propellant has been based on nitrocellulose - I refer to double base, single or triple base compositions - you know that if ever any item is suspect as to its state of deterioration or its condition, you can send that piece of hardware or sample of the propellant to some laboratory where they will conduct a series of tests which are commonly accepted for this class of material. The tests I refer to are either the color indicator type that depend on a combination of oxidizing gases and moisture or the gas evolution type. By the color indicator type I refer to the classic methyl-violet heat stability tests. By the gas evolution type I refer to the vacuum stability or tyronic type tests. There is still a third, the available stabilizer type tests which depend on how much diphenylamine or diphenylamine capable of nitration is still left. These tests have been around now according to the literature for practically 3/4 of a century. They have changed very little from their inception. This is not a defense of these tests, as a matter of fact there is a growing body of criticism as to what they really do test when you put this suspect piece of propellant under them. However, they do exist, they are all we have and the fact is that if they are properly applied and conducted under rigid empirical conditions in the laboratory, you will grossly find whether the piece of propellant is still good - that is safe - or whether it is partially deteriorated. The difficulties come in when attempts are made to extrapolate these to how many years of life you have left and I'm not getting into that can of beans. I painted one picture and this is commonly done, a surveillance type operation. Now that the composite oxidizer-fuel types are here, put yourself in the same position again. There is a piece of hardware where you feel that due to certain conditions, the propellant is questionable, whether it is deteriorating or not. We send this item or a sample of it, the propellant I refer to, back to the laboratory for a chemical stability test and you will get a rude jolt. There is no chemical stability test that is accepted by the industry for composite oxidizer fuel propellants and we have to understand that beginning with the early potassium perchlorate asphalt types, composites have now been on the scene for close to twenty years. There is no test existing that all accept as a standard. The organization that I'm working for, Frankford Arsenal, develops ejection devices - propellant actuated devices ranging from tiny initiating cartridges to rocket ejection systems for pérsonnel payloads. Some time ago we found out through field tests and from samples sent back from the field, that in certain instances these items were being subjected to severe

heat. These systems are based on nitrocellulose based propellants. We found that they would not take temperatures above 165° F. and we are still in the process of abandoning those systems and we look for more thermally stable propellants. This meant we went over to the composite oxidizer-fuel type. As of the last count that I had, we had 18 individual compositions and I do not refer to the same oxidizer and fuel with variations of a per cent or two. I mean 18 combinations of oxidizers and fuels. Then we wanted to apply a common test to these and we ran head on into this little gap and there was simply no ducking it, no turning away. We simply had to devise some means to find it out. The question is, why is there no test. This is not a matter of oversight, it's a matter of the nature of the beast which defies the men. For example, let's just take oxidizers. The work horse oxidizers in existence today you all know are ammonium perchlorate, ammonium nitrate, or potassium perchlorate. When we turn to the organics, they are the common commercially known organics. I have a little listing of them here I'd like to read off and you'll get an idea. They include cellulose acetate, butadiene methyl vinyl pyridine, butyl rubber, ethyl and butyl formal polysulfides, polyurethane, alkyd styrenes, polyvinylchlorides, polybutadiene acrylic acid, epoxys, fluorocarbons and this I would say just about classifies the work horse binders and let us now add to this, what is in the laboratory which hasn't quite emerged, and I refer to combinations of boron, oxygen, fluorine, nitrogen, etc. It's small wonder then when the chemist in the laboratory attempts to get one criteria by which to measure all this, he sort of recoils in horror. We simply could not recoil. There have been a number of tests which were suggested as neutral to this wide variety of chemical species. The tests include combinations of the following: attempts to take gas evolution tests of adiabatic propellant gases, but in truth these are not very neutral; and differential thermal analysis known by now as DTA which is a good laboratory tool. It points out exotherms and endotherms in the composition, but there is still no frame of reference that covers this wide jungle of chemical species. Auto-ignition tests - and I have a good body of literature to show that there are at least 15 to 20 individual auto-ignition tests being run by the field today - and then tests of what they refer to grossly as binder depolymerization - i.e., if you have what they call a "cross-link polymer" and it is degraded somewhat then you can extract part of it with salt, and the idea is now to quantitatively establish how much of it is extractable. Of them all, a couple that appeared the most feasible to us were to try to apply a gas evolution test or a binder swelling test, i.e., what would be extractable. These are all chemical stability tests. Actually in the composite field, the most advances have been made in the measurement of mechanical properties. Its elastomeric properties are known when the propellant is first made and after a certain amount of aging how much of that original elongation or elasticity still exists. But my subject here is chemical stability

test, not truly a mechanical test. We did a lot of new work along these lines as I mentioned earlier - we didn't solve it - but we did come up with some information which will just show you the kind of struggle we're up against and if anyone attempts to do it what he's up against. I have about four or five slides which I will show you in order. This technique we worked out simply involves a matter of canning a piece of propellant. The piece you see here is approximately ½" diameter, about .6" high. It averages 3 grams and we have standardized the size of the propellant. What you see here is an aluminum capsule. We put the propellant inside, put the cap on top and then by a patented process of Kelsey-Hayes, they refer to it as "cold-weld," will actually hit this with a shaped punch and die and this is what you get here. A piece of propellant is as effectively canned as a can of soup - it's hermetically sealed. The attractiveness of the situation is that there has been no heat applied in this welding proposition. Now we have a sealed sample of propellant. We take these propellants and subject them to whatever conditions we want, either lie around, freeze them, heat them, do what you want. They are able to track the gases that come off above the level of the propellant and the idea now is to analyze what this atmosphere is. The next slide shows a propellant and this is a mass spectrometer analysis. I have another one to show you later on and I want to pinpoint the differences to watch out for. Here at the top you have the classic air analysis, so much oxygen, so much carbon dioxide, nitrogen, moisture omitted. The control is really a piece of propellant canned as you see it, no heat applied. This is the analysis of the atmosphere above that piece of propellant, fairly close to what regular air would be. When we subjected this propellant to heat for extended periods, you see what happened. The oxygen content drops, carbon dioxide builds up, although as you can see it's not particularly linear, the nitrogen content - because this is a mole per cent value - drops in proportion. We started to measure hydrogen relatively late, we should have had some figures up here but you can see they run about 1% or so. To sum up this particular picture, what I want to point out is the depletion of oxygen in the air which means the binder is being oxidized, the evolution of carbon dioxide in that carbon can come only from that binder. The next slide is an infra-red spectrum - I won't go into the chemical details - and each peak to those who may not be familiar represents a particular chemical species in a binder. The point that we want to make here is that we extract portions of the binder which has been more severely exposed in this particular propellant, you get a gradual increase from it which would appear that there is a certain amount of degradation that has taken place in the binder. All that the various curves show are that there have been no new species evolved. They are all identical. In other words what is extracted at the beginning

retains its chemical identity and just more of it comes out. On the chart you'll notice that it may be very small but the unexposed 3, 6, 9 and 12 hour heats are right in order. The next slide shows a second composite propellant. The previous propellant was a polyurethane based binder propellant. These both contain ammonium perchlorate and this one has an epoxy based binder. Notice once again for comparison the typical air, but beginning here we begin to run into a little trouble. Notice that the propellant just as it sits sealed has already begun to absorb some oxygen from the air. Some oxidation of that binder is now in progress and we haven't even heated it. I may add incidentally that the particular capsules that this took place with were sealed as you saw and sat around in the laboratory at ambient temperatures for about five weeks before we were able to get to work on this particular one. Notice again the sharp drop. We are in every instance down to very minute amounts of oxygen left. It has absorbed practically all of the oxygen out of the system. But whether she has taken more oxygen out, there has been considerably less carbon dioxide evolved wherein the other propellants you saw that there is 20 to 30 odd per cent carbon dioxide coming off, the conditions are identical. The same heat and the same time periods put out less carbon dioxide. Now this throws this figure off. You may say, well we started with 78% nitrogen, we're getting these larger quantities. The propellant is not giving off nitrogen as it degrades by the relative lower per cent value since oxygen was absorbed and less CO_2 came out, this figure is now proportionately higher. Another interesting thing, notice that the moisture comes out and a considerable evolution of hydrogen was picked up in this spectrum. The next slide - again to point out that there are no differences in what comes off the propellant except that there is no general progression in how much is extracted. The more you heat it - the amounts stay roughly the same with very little difference. That's all the slides. The next picture here, there are just two typical samples of the kinds of data you get. From two composite propellants as they degrade they absorb oxygen slightly differently. They give off different amounts of carbon dioxide, they are extractable by silence in different proportions, does not literally follow the amount of deterioration at the foot. In effect then there are certain conclusions we can draw. Any chemical stability test for the wide range of composites or for any propellant for that matter, must depend on either the appearance or disappearance of some chemical species during that propellant flight. What is native to all of these is carbon. Two figures show here; one that oxygen is absorbed; two that carbon dioxide is emitted. I would like to go out on a limb now and state that if ever a chemical stability test should be formulated which would be considered an acceptable yardstick for them all it would have to be a conservative one and based on either oxygen absorption or evolution of CO_2.

The common ground work will have to be laid in wide patterns to cover the wide variety of propellant. In summary, we've done a little work towards it, our answers are largely negative, but as of today there is no laboratory test that can be called a stability or a state of condition test for composite propellants and although this is an effort by an agency with an individual problem, I feel that a body such as the JANAF surveillance panel, perhaps, and others should sort of carry the flag for an industry-wide effort towards some standardization. There is none that exists today. Thank you.

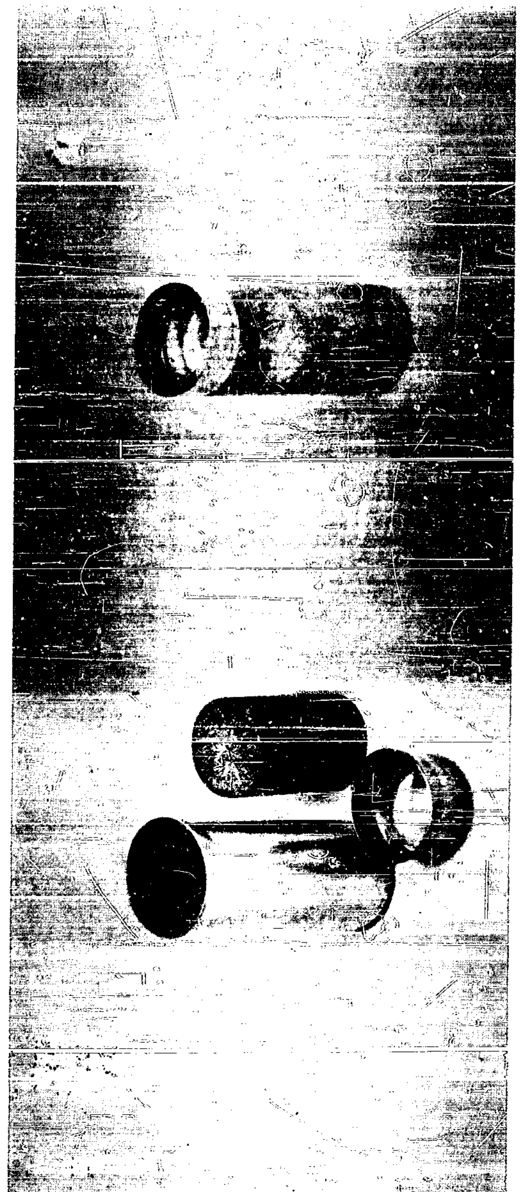


Figure 1. Hermetically Sealed Propellant Capsule

MAJOR GAS COMPONENTS, CAPSULE ATMOSPHERES
FROM HEATED COMPOSITE PROPELLANT

(Values in mole %)[a]

Exposure	O_2	CO_2	N_2	H_2O	H_2
Typical Air	20.9	0.0	78.1	-	-
Unheated control	19.6	0.1	79.5	-	-
3 hrs./300° F (A)	5.4	24.5	66.4	tr.	-
3 hrs./300° F (B)	5.3	23.2	68.4	tr.	-
6 hrs./300° F (A)	0.9	34.7	61.2	tr.	-
6 hrs./300° F (B)	0.9	33.4	60.2	tr.	-
9 hrs./300° F (A)	3.8	26.3	68.7	1.3	1.1
9 hrs./300° F (B)	4.5	25.7	67.9	0.2	1.1
12 hrs./300° F (A)	1.4	31.1	66.7	0.9	1.1
12 hrs./300° F (B)	2.4	31.0	64.5	0.1	1.2

[a]Argon and trace quantities of impurities omitted.

Figure 2. Major Gas Components, Capsule Atmospheres from Heated Polyurethane Composite Propellant

Solvent Extractable, % by Wt.	
Unexposed control	4.0
300° F/3 hrs	7.3
300° F/6 hrs	11.2
300° F/9 hrs	12.8
300° F/12 hrs	15.3

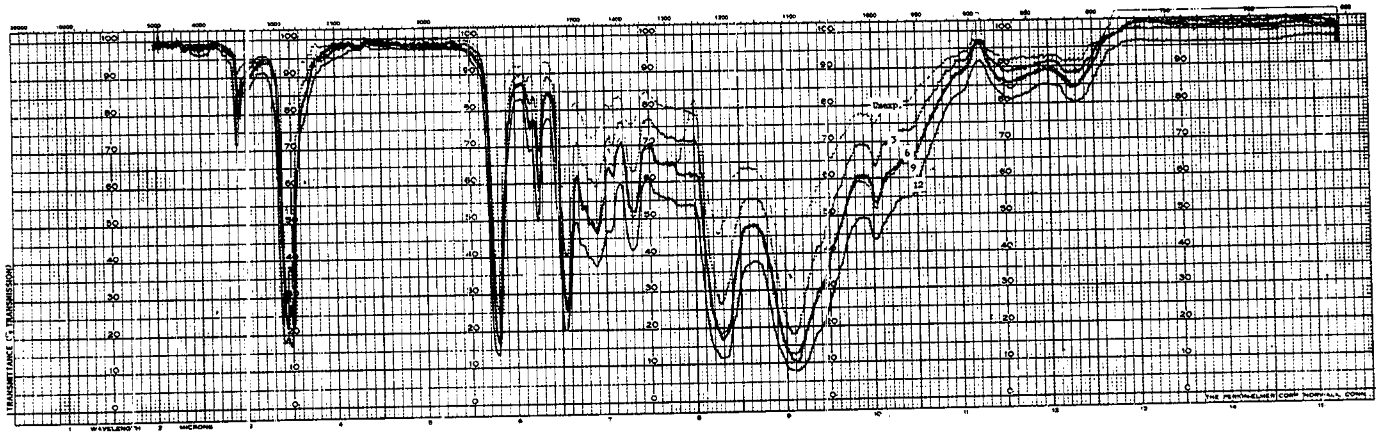


Figure 3. Infrared Spectra, Solvent Extracts of Heated Polyurethane Composite Propellant

UNCLASSIFIED

MAJOR GAS COMPONENTS, CAPSULE ATMOSPHERES
FROM HEATED COMPOSITE PROPELLANT

(Values in mole %)[a]

Exposure	O_2	CO_2	N_2+CO[b]	H_2O	H_2
Typical Air	20.9	0.0	78.1	-	-
Unheated Control (A)	15.1	0.6	83.5	0.3	0.3
Unheated Control (B)	14.4	0.6	83.9	0.8	0.3
3 hrs./300° F (A)	0.3	12.7	84.3	1.2	3.0
3 hrs./300° F (B)	0.2	13.0	83.5	1.0	3.3
6 hrs./300° F (A)	0.1	13.8	81.6	1.0	4.7
6 hrs./300° F (B)	0.1	14.3	81.4	0.5	5.1
9 hrs./300° F (A)	0.1	14.3	80.2	0.4	5.1
9 hrs./300° F (B)	0.2	14.1	79.5	1.0	6.0
12 hrs./300° F (A)	0.3	13.9	79.7	0.3	6.2
12 hrs./300° F (B)	0.4	13.8	79.5	0.3	6.1

[a]Argon and trace quantities of impurities omitted.

[b]Attributed primarily to nitrogen; quantitative CO not given due to masking by N_2 peak at mass 28.

Figure 4. Major Gas Components, Capsule Atmospheres from Heated Epoxy Composite Propellant

Solvent Extractable, % by Wt.	
Unexposed control	6.3
300° F/3 hrs	7.0
300° F/6 hrs	7.6
300° F/9 hrs	7.6
300° F/12 hrs	7.5

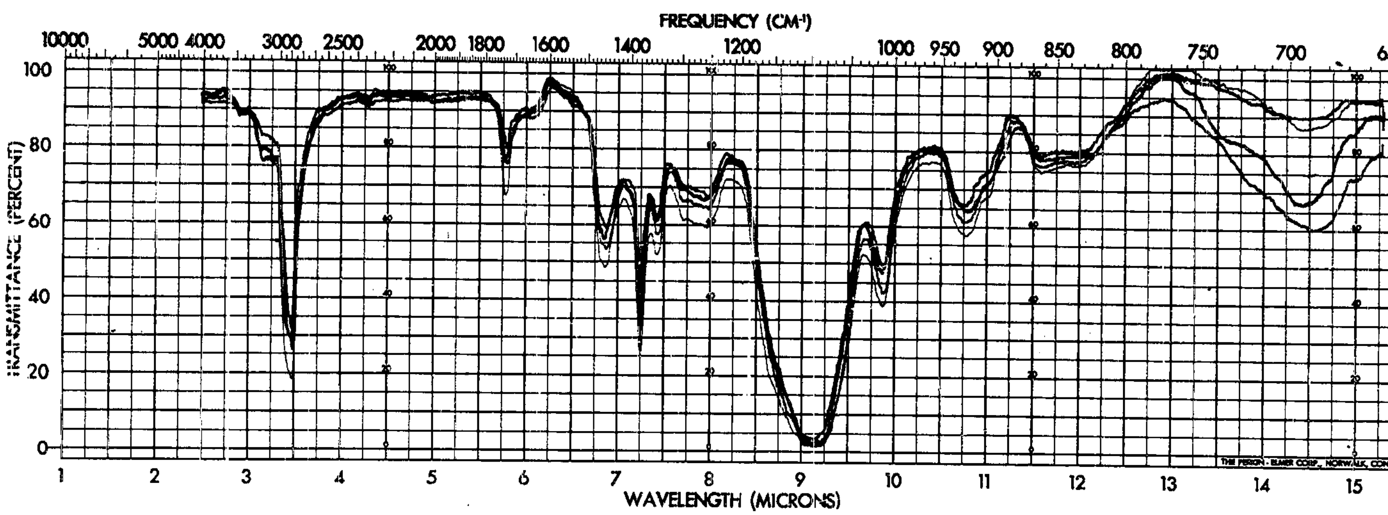


Figure 5. Infrared Spectra, Solvent Extracts of Heated Epoxy Composite Propellant

UNCLASSIFIED

Mr. Saffian: Do you think that the propellant gases are reacting with the casing - with the aluminum?

Mr. Visnov: We've run numbers of trials by just taking bare aluminum capsules and with just atmosphere - the amount of oxygen depletion is very little, that is, the aluminum forms its typical passive oxidizing surface and just stays. The oxygen content does not keep dropping.

Mr. Saffian: No, I mean -

Mr. Visnov: The propellant reacting with its sheet aluminum? I would not feel so. These two particular propellants incidently happen to have powdered aluminum in their formulations which is common practice today with most composites. They're loaded with about 15 to 18% aluminum already. That aluminum powder you refer to may be a catalytic agent, but not the aluminum of the capsule.

Mr. H. F. McQueen, Thiokol Chemical Corp.: You indicated from the title that you were attempting to assess the thermal stability of these propellants, I assume after long term storage with the objective of determining if the sensitivity increased or the auto-ignition temperature decreased. Are you aware from your work or others of any change in the auto-ignition temperature of perchlorate-hydrocarbon binder propellants?

Mr. Visnov: I believe the data I showed here was not based on auto-ignition temperatures. If I recall correctly I believe there is someone on the agenda here who will go into that at length. We have not done that particular work. We have done a considerable amount of auto-ignition testing but not after storage - just on fresh propellant for judging the comparison. I'd be very interested in hearing this gentleman's results later on.

Mr. McQueen: A considerable amount of work has been performed in assessing the degradation of composite propellants, particularly perchlorate propellants, to determine the performance of said propellants in a pilot plant. But I'm not aware of any in which the result showed a hazard that might develop on storage. This is perchlorate propellants now. Maybe I misread the title of your dissertation.

Mr. Visnov: Not sensitivity. Do you refer to auto-ignition or ignition in a propellant item?

Mr. McQueen: Auto-ignition.

Mr. Visnov: No, we did not.

Col. Hamilton: Thank you very much Mr. Visnov.

Our next presentation will be by Mr. R. C. Herman of the ASESB 'Standard Test Criteria for Determining Hazard Characteristics of Rocket Motors' Mr. Herman.

Mr. Herman: Mr. Marsh, Colonel Hamilton, Gentlemen. I would like to tell you what the Armed Services Explosives Safety Board is doing towards the development of criteria for standardizing the testing of propellants to determine the hazard characteristics of solid propellant rocket and missile motors.

First, I would like to give you a little background regarding this. Up to a few years ago there were no uniform tests conducted by military activities to establish the hazard classification of ammunition and explosives items. In an effort to standardize testing of these items the Board formed a work group to develop minimum test criteria. The work of the group resulted in the issuance of a joint regulation entitled "Explosives Hazard Classification Procedure" dated 15 October 1959 which gives test criteria for all types of ammunition and explosives items and is used by the Army, Navy and Air Force.

When this document was being developed by the Work Group, we experienced trouble in determining what tests should be included for solid propellant motors. There were many tests being conducted but sufficient data has not been obtained to prove the tests valid. Also the tests that were being used were conducted differently at each facility, therefore, correlation between them was not possible. For this reason very little information regarding tests on solid propellant motors is given in this document.

Questions regarding the classifications of various solid propellant motors continued to be raised, and inquiries regarding tests were constantly being asked of the Board. Therefore, in the spring of 1960 the Board extended the mission of this Work Group to develop minimum test criteria to determine hazard characteristics of solid propellants during the research and development stage. Also the membership of the work group was expanded to include not only the Army, Navy and Air Force but also NASA, Bureau of Explosives and the ICC. Personnel from the safety offices as well as technical personnel from the field were requested to participate in these meetings.

This work group attacked the problem by determining:

a. What tests are required, for example, by the ICC.
b. What types of tests are presently being made by both contractor and Government agencies.
c. What type of information is desired.
d. What type small scale tests could predict the characteristics of the full size motor.
e. What are the actual hazards of a missile when sited for flight tests and tactical deployment.

Work Group members were requested to obtain from their Services' contractors test criteria used by them in testing propellants. This information was used by the group during their studies, and some of you are probably aware of the information submitted for this purpose. During periodic meetings held by the group, answers to the above questions were considered, and tests designed to answer these questions were developed. During the development of these criteria, an attempt was made to include tests which are presently being used by the Bureau of Explosives, private contractors and/or Government Proving Grounds, with the primary objective being to standardize tests in order that the results could be correlated regardless of which agency conducts the tests.

This test criteria is broken down into four phases, with each phase being conducted at a given point during development. The phases are:

Phase I - During Laboratory Development by Contractor

Phase I has been divided into two segments - IA and IB. In IA, 10 gram samples are used. These tests are essentially those required by the ICC but on a smaller size sample. In IB, samples required by ICC are used. These are the ICC tests.

Phase II - During Propellant Development by Contractor or Government

These tests are conducted to determine critical diameter, sensitivity as indicated by card gap, reaction due to external heat, and reaction to bullet impact. In the two latter tests, 5-inch work horse motors filled with the candidate propellant will be used. On the larger (8") critical diameter test percentage of propellant contribution to air blast can be determined with standard equipment.

Phase III - During Motor Development by Government

These are detonation, external heat, bullet impact and drop tests, in which only full size motors will be used.

Phase IV - During Missile Development by Government

These tests are not mandatory, but may be used by any Service to obtain hazard characteristics of a missile. Such information could be used for tactical siting or for locating flight test launch pads. The primary effort in this area is to standardize these tests, if used.

Now, a word or two concerning the status of this document. We are presently getting this document in final form, however, we still have some work to do on it. There has been unanimous agreement, by

Work Group members, on Phases I, III and IV. We still have questions to be answered in Phase II. As I indicated earlier, Phase II includes critical diameter and card gap tests, as well as others. We plan to establish a dividing line between fire hazard and detonation hazard in terms of numbers of cards which will prevent detonation in the card gap tests. Most all work done with the card gap test has involved military explosives and propellants. Some work is necessary on commercial explosives and propellants to be sure that any dividing line selected on the card gap tests to divide mass detonating explosives from fire hazard explosives will correlate with past experience gained on the commercial explosives. The Bureau of Explosives, AAR, is working in conjunction with the Naval Ordnance Laboratory testing additional samples. When these tests are completed, a recommendation will be made regarding this dividing line.

At this point I would like to stress the fact that to date we still do not have sufficient data on all of these tests to say "these are the only tests to use." There are other tests being conducted which show promise and perhaps as time goes on, even others will be developed.

What we are attempting to do at this time is to take the tests which are required and those which show promise and standardize them so that the results can be correlated. We know that as we gain additional experience, we will have to modify this criteria.

It is hoped that after a year or so sufficient data will be available from the critical diameter, card gap and other small tests to eliminate the requirement for tests of full size motors. Of course, with the prospect of future motors of multi-million pound thrust the cost of full size testing would be prohibitive even if we could find a large enough land area to conduct such tests.

It is difficult to predict just when this document will be available to you. As was just pointed out, we still have some commercial explosives to conduct card gap tests on in order to make our decision about a dividing line between Class A and Class B. Then we have to prepare a final draft for submission to the Board for consideration. If the Board approves the document, it must then be forwarded for the normal review and coordination. When this is completed there is still printing and distribution.

This concludes my presentation. Are there any questions?

Dr. Ockert: Today all the propellants we use are poured into a tin can in a fluid state and then they go through some sort of a cure process. I believe that to get this 100% reliability in any sort of screening test, you are going to have to consider some sort of

non-destructive inspection of every single round. Because if you have carloads of units, even though they may pass all the tests for perfect motors, if you have one in there that is imperfect then you get this nightmare. We at Rohm & Haas remember this most bitterly - what is called DDT - this transition from fire to detonation. You have a thankless job and your efforts are greatly appreciated but I think you're going to have to remember the possibility for error from one round to the next.

Mr. Herman: I can appreciate this, however, I think the area in which you are speaking is more one of quality control of the individual items than it is the hazard classification of the group of items. Is this in the area of which you are speaking?

Dr. Ockert: This is true, but we can have a group of items and all of them have passed inspection before you can give the Good Housekeeping Seal of Approval.

Mr. Herman: Oh yes.

Mr. Ullian: (first part of sentence not recorded) ...motors that we're talking about, 140 to 260" diameter motors with liquid upper stages, liquid hydrogen, liquid oxygen that can detonate and give you maybe 100,000 pounds TNT equivalent or a pressure equivalent to 100,000 pounds in the upper stage. How do we run a hazard classification test on something like this? Or occasionally we have solid propellant motors surrounded by liquid propellant systems, completely surrounded except at the base?

Mr. Herman: This is the reason why we have to stop at some point and start gathering information. You heard Dr. Noonan speak earlier of the work that has been done on card gaps, what they can gather from this to date. We know very well that we can not take these multi-million pound thrust engines and run full scale tests on them. So we hoped that by running these tests, go ahead and standardize what we have now, that we can get sufficient information and have enough confidence in these tests that we can answer your question without going into these big motors.

Mr. Ullian: Can I ask you when this will be available, because in about five months we'll be siting these launch pads?

Mr. Herman: I would estimate around the first of the year is about the earliest we could expect this.

Mr. Ullian: I might emphasize that this is an area that has been lacking and I'm afraid it's going to end up being best guestimate when we start siting these because the siting could have been done a year ago, but it looks like it's going to get started in about 4 months.

Mr. Herman: I realize this and this is one reason why the Board was very anxious to get something out. We realize it maynnot be the b st thing, but let's get something started so we can start getting some answers. If we keep waiting, trying to get the very best available, we'll never have anything.

Mr. Jezek: As we pointed out in our original bulletin, which was TB 700-2 I think, we didn't have enough knowledge on the large scale motors and I think that when we get into the realm of motors weighing so many tons, as far as I'm concerned, I think a man is just as dead when he's burned to death as he would be from blast. And it's my opinion that these large scale motors should all be set under Class 10 hazard.

Mr. John Zampatti, Wright-Patterson AFB: We are vitally interested in this hazard classification problem. One of the questions was already posed by someone else. I'm vitally interested in this document which you were referring to, which gives us some feel as to what can be considered standard test criteria. Unfortunately we can't wait. We are feeling our way along this direction. I would like to find out what are you people right now recommending as the minimum test criteria for establishing an official or semi-official hazard classification for power type motors?

Mr. Herman: I would like to answer this by ducking the question. You have representatives on this group from both Edwards AFB and from Hill AFB and I would much rather that they make the decision as to what portion of this they want to use right at this time until it is standardized, rather than me make the decision.

Mr. Zampatti: I'm not asking you for a decision. I'm merely asking for a feeling as to what direction the Board is going in this area right now?

Mr. Herman: I have outlined it to you, I would be glad to show them to you after we finish, exactly what the status of the document is and what the various phases consist of if this would help you.

Mr. Zampatti: That would be fine.

Mr. Bishoff: In answer to the question from the Air Force representative, if you are going to apply the distance from a fixed site and you want to determine the inhabited building distance, the only criteria that I think you may honestly use at this time is to subject the motor to the detonation of the HE warhead and find out how much blast contribution comes from the motor.

Dr. A. M. Ball, Hercules Powder Co.: Two questions that maybe you can answer yes or no. Pending the issuance of the new document, is or is not TB 700-2 still the official word on this question?

Mr. Herman: Yes, you are correct. TB 700-2 is an official document which is in existence. Now, whether this new document will be an addendum to it or whether it will be a change to it or a separate item, I cannot answer at this time. However, specifically TB 700-2 is the official document at this time.

Dr. Ball: My second question has been asked before. Wouldn't it be possible to get in memorandum form these that you think are going to be in a mixed document so that those of us who are now setting up hazard classification programs can get a jump?

Mr. Herman: I think if this request were submitted to the Chairman of the ASESB and the Board decided we would go ahead and give this information, there's no reason why we couldn't.

Col. Couch: This document referred to as TB 700-2, the Air Force designation is Technical Order 11-A-1-47.

Mr. Herman: I would like to point out one other thing I think came up last year that I think might please Dr. Ball. In this present document there is a requirement for a 30 gram tetryl pellet which a lot of people have experienced difficulty in obtaining, a 30 gram tetryl pellet of these particular dimensions. In the new document we are contemplating changing the booster in these tests to a pentolite which can, of course, be poured in practically any size and come up with something that you can correlate, whether you want a small test or a large test, if you use the pentolite booster.

Mr. H. Ackerman, AFSC: To answer the question from Mr. Zampatti on the minimum test criteria, in addition to the Tech Order that was quoted by Col. Couch, if any additional information is needed, he should go to the headquarters.

Mr. Endsley: I want to re-emphasize that for the people connected with Air Force procurement, production and R&D, the Tech Order is 11-A-1-47. If this does not meet the minimum requirement that you're trying to achieve, then query your systems command or the Deputy Inspector General for Safety. If you're subordinate to the Systems Command, go thru them to us, at Norton AFB. The problem that Mr. Bishoff brought up concerning the detonation of the warhead in the tactical configuration, the gentleman's question pertaining to the 87, does not follow this configuration. This is an aboveground situation, however, we do have a system in being that will be belowground environment and we can resolve the specific questions thru the Systems Command to the DIG for Safety

if you want to get more detail that is not currently included in 11-A-1-47. We have the advantage of having some of the preliminary documents that the Board is putting out on the minimum test criteria and we have participated in the work groups. However, we cannot sanction these as official Air Forcekpositions until they have been approved by the Secretary. Therefore, we can apply them as Air Force criteria on an interim basis but it cannot be accepted as a DOD policy until Secretarial approval.

Col. Hamilton: Thank you Mr. Herman. Mr. R. H. Richardson who is directly associated with the sensitivity and detonability investigations at the Allegany Ballistics Laboratory of the Hercules Powder Co. will discuss an 'Infra-Red Method of Distinguishing Shots and Failures for Impact, Friction and Electrostatic Sensitivity Testing of Combustible Materials.'

Mr. Richardson:

Determining if initiation of some degree has occurred during sensitivity tests of combustible materials has been a problem that has plagued investigators for many years. The ability to distinguish shots and failures accurately and consistently is extremely important whether the experimenter is carrying out academic studies, establishing data for comparison purposes, or determining absolute values for the purposes of application to specific problems. Past efforts where the "noise" level was selected as the criterion have been reasonably successful.1/

However, for reasons of safety, the decomposition level has been selected as the criterion for impact, friction and electrostatic discharge sensitivity testing at Allegany Ballistics Laboratory (ABL). With the selection of the decomposition level, it is realized that differentation between the occurrence (shot) and absence (failure) of decomposition would be difficult for the operator to accomplish.

A shot has been defined as follows: "Any decomposition of the test sample as evidenced by smoke, fumes or odor, sparks or flame, audible noise over and above the normal testing noise, and as indicated by visual examination of the sample and surfaces of the metal components for flame trace after an impact, friction or electrostatic trial."

In the use of the above definition it was realized that not all decomposition products are characterized by odor or smoke, and that it is hazardous for personnel to inhale such products. Difficulty can also be experienced in differentiating between a stain or flame trace, and a smear on a metal surface. Also, dust and mist can be mistaken for smoke and the ability to use the above definition may vary from operator to operator. The problem of differentiation is further compounded by the fact that ABL attempts to establish as closely as possible the zero initiation (decomposition) level (ZIL), not the 50% probability level. Thus, because of the lower input of energy, there are fewer of the decomposition products that can be used for detection purposes.

Since the decomposition products are gaseous in nature and the initial stage of decomposition is of interest, the detection of these gaseous products is considered a reasonable method of establishing the zero initiation level.

Three methods were considered: (1) measurement of a pressure change, (2) measurement of the change in the thermal conductivity of the air around the sensitivity test apparatus, and (3) measurement of the change in the infrared absorption of the air surrounding the sensitivity test apparatus.

The first method, although successfully used by the British[2/] for impact testing, does not lend itself to friction testing or the specific type of electrostatic testing conducted at ABL. This method also involves a high degree of confinement for impact testing which was highly undesirable since unconfined testing was of primary interest at ABL.

Measurement of the thermal conductivity of the gases was investigated since equipment was readily available and considerably less costly at the time. The Perkin-Elmer thermistor and Gow-Mac hot wire types of thermal conductivity cells were investigated. Although both types were successful in detecting the gaseous products, neither was feasible from a practical viewpoint, because of the deterioration of the elements caused by the corrosive properties of the decomposition products.

During the latter phases of the above work it became known that the Mine Safety Appliances Company (MSA) had available a relatively inexpensive Lira-300 Infrared Analyzer (Figure 1) designed primarily for continuous analysis of gases or liquids in concentrations of one percent or greater. On the basis of availability, relatively low cost (less than $2,000), portability, and the fact that detection of gaseous products at concentrations as low as 0.01% appeared feasible, the Lira-300 was selected as a possible method of establishing the presence of decomposition products.

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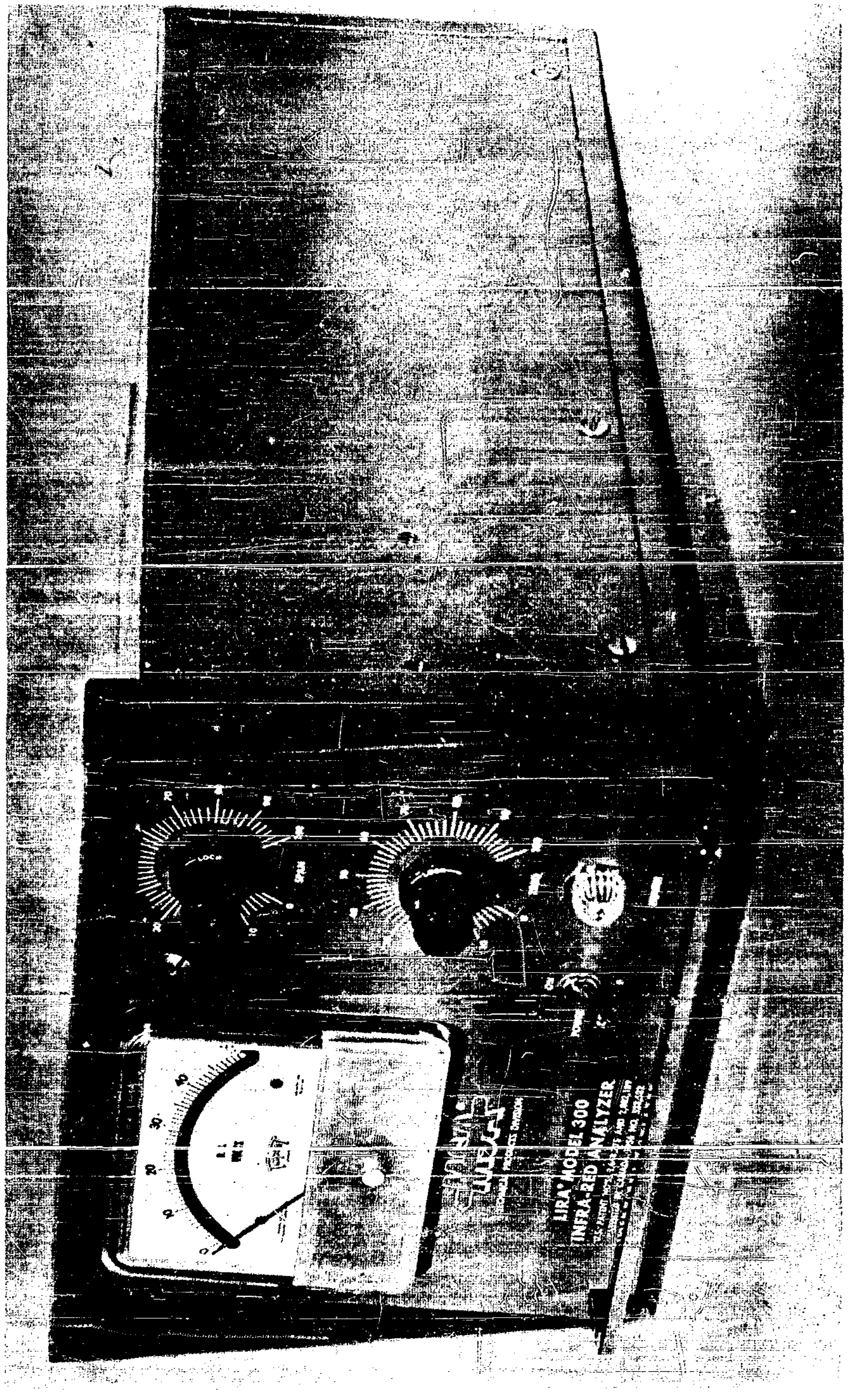


FIGURE 1
Lira-300 Infrared Analyzer

UNCLASSIFIED

LIRA MODEL 300 INFRARED ANALYZER

The operation of the Lira-300 (Figure 2) is such that two identical infrared beams are directed through the gas cells. One cell contains the known comparison gas, in this case, room air. The other cell contains the air immediately surrounding the sensitivity test apparatus, including the gaseous decomposition products if a "shot" has occurred. After the beams pass through the gas cells they are directed into a single detector unit that contains the sealed-in detector gas (a sample of that gas for which the unknown is analyzed). Usually only one gas is used in the detector cell. However, since the analysis is qualitative rather than quantitative, only the "presence" of the decomposition products is required and N_2O, NO_2, CO and CO_2 are included. These gases are enclosed in the detector cell, since the production of one or more of these gases could be expected if decomposition were to occur. This was established experimentally by collecting the decomposition products from known shots, using materials representative of those used in the manufacture of cast propellants, and analyzing the gases using an infrared spectrophotometer. As the gases in the detector unit absorb the residual infrared radiation, there is an accompanying temperature and pressure increase within the cell. The increased pressure moves a sensitive membrane in the detector unit. This movement is converted by the electronic amplifier to an output signal which in this apparatus is in turn displayed on a meter. The measurement of the absorption of the gases in the sample cell is accomplished by using a beam interrupter to alternately block the infrared radiation from each source. This permits only one beam at a time to pass through the gas cells and enter the detector unit. Thus the detector gas expands and contracts as the beams are alternately blocked and directly indicates the energy difference of the two beams.

The instrument is a dual range unit allowing measurement in the ranges of 0 to 0.2% and 0 to 2.0%. For this investigation the unit was used at the low range only to obtain maximum sensitivity from the instrument. Calibration by MSA showed that 1% NO_2 would only read 45% full scale on the low range setting. Therefore, for this work it was assumed the detection of decomposition relied on the absorption of CO_2, CO & N_2O. The calibration curve provided by MSA is shown in Figure 3. No attempt was made to check the calibration as shown in Figure 3 during this testing, although the instrument was calibrated using room air prior to each test. The lack of the check on the calibration curve should not significantly influence the test results here, since the only effect should be a small change in the actual concentration of the composite gases as indicated by the meter. For the purpose of this investigation, the movement of the meter needle two graduations or more after a trial was considered a shot. According to the calibration curve this would indicate the presence of CO_2, CO & N_2O, either singularly or in combination, in concentrations of 0.008% or more.

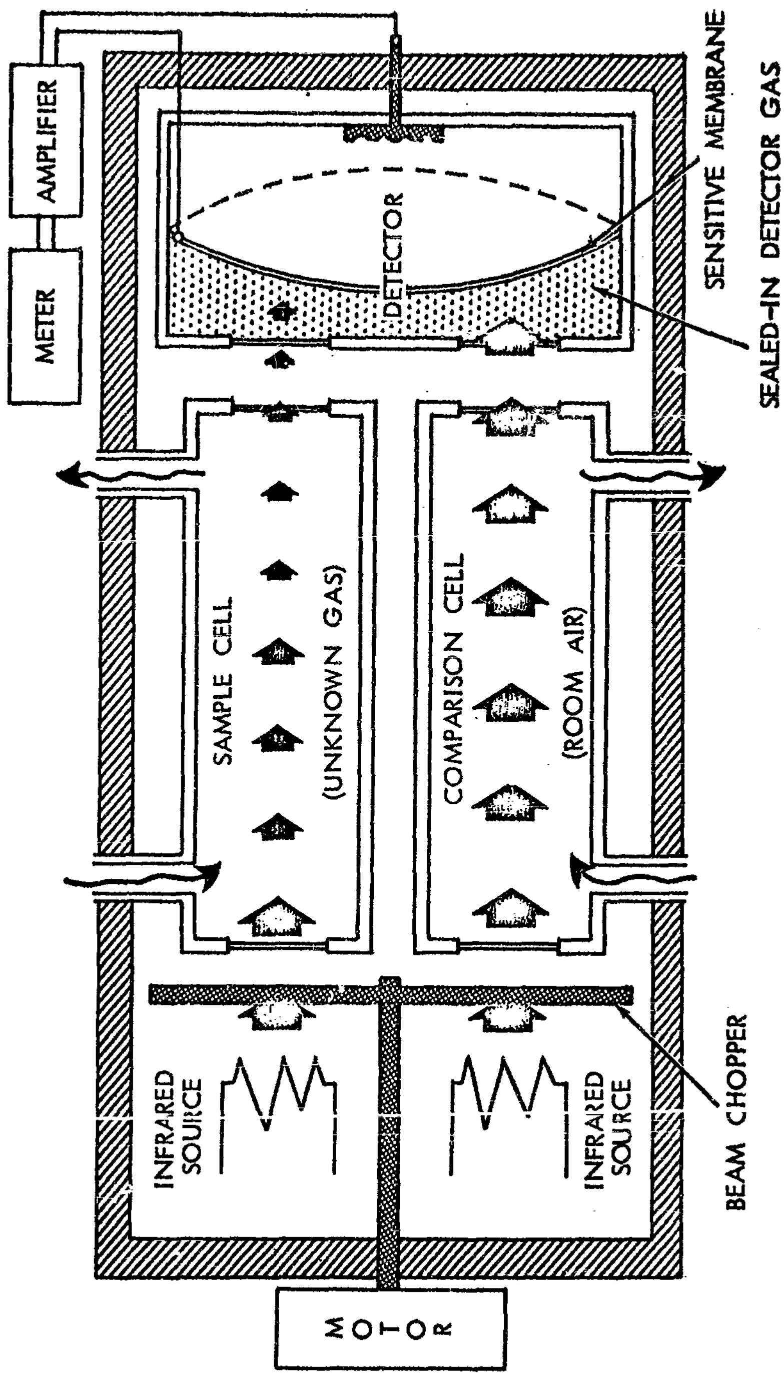


FIGURE 2
Lira-300 Infrared Analyzer

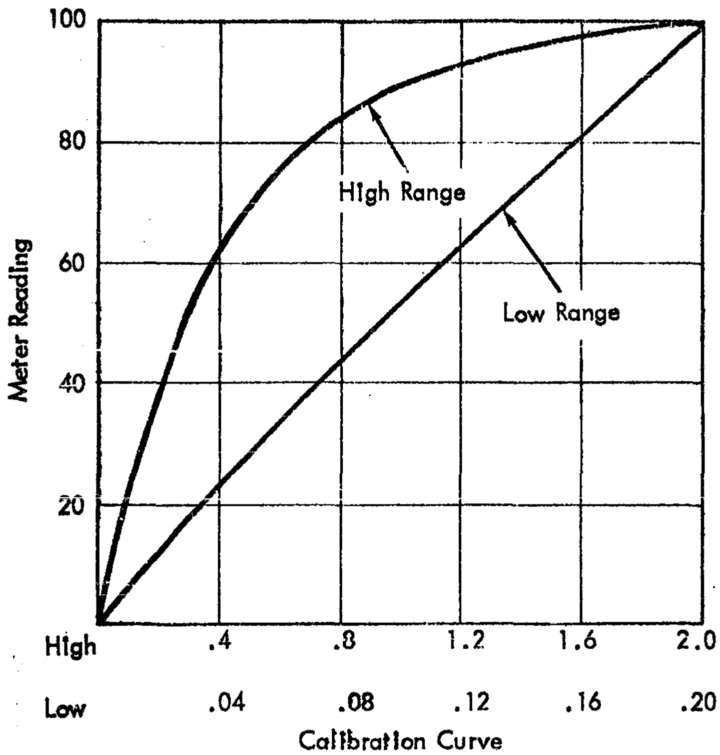


FIGURE 3
Percent Carbon Dioxide, Carbon Monoxide, Nitrous Oxide

A schematic of the experimental setup consisting of vacuum pump, Lira-300, in-line solids filter and valves, is presented in Figure 4. To minimize the corrosive effects of the decomposition products, Stainless steel cells and calcium fluoride windows were used. The operation of the Lira-300 was such that both room air and air from the vicinity of the impact anvil and hammer were continuously drawn into the sample and comparison cells at the same rate (2800 cc/min). This flow rate was selected on the basis of preliminary data which indicated that the response time of the Lira-300 would be optimized at approximately 2800 cc/min.

EXPERIMENTAL

For this investigation the ABL Impact Machine was selected as the mode of initiation. The ABL Impact Machine utilizes a variable drop height with a 2 kg drop weight. Basically, the falling weight is used to impact a monolayer sample between two stainless steel impacting components; the hammer (0.5" diameter) and the anvil. The combustible materials tested were: (1) composite modified double-base casting powder, (2) nitroglycerin, (3) double-base propellant and (4) nitrocellulose. These samples were selected on the basis of previous experience to cover the range of difficulty in distinguishing shots and failures, and of being representative of the materials used in the cast propellant process. Testing was conducted by the increment method utilizing three different operators on each material. Zero initiation data typical of an increment method test using the impact machine are shown in Table I. The zero initiation level is defined as the level above which initiation can occur as established by twenty consecutive failures obtained at that level. All operators had completed the training necessary for operation of the impact machine and were chosen to cover a wide range of experience in such an operation.

In these tests, the air was collected using a suction hose placed one inch from the interface of the anvil and hammer and in the same horizontal plane. A small cellulose acetate tube (2-1/4" OD X 4-1/4" L) open at the top was used to surround the anvil and hammer assembly in an attempt to confine the gases effectively to a smaller volume during the critical air sampling period after a shot. Although fragmentary data indicates this confinement improves the sensitivity of the Lira-300, additional testing will be required to establish the validity of this observation.

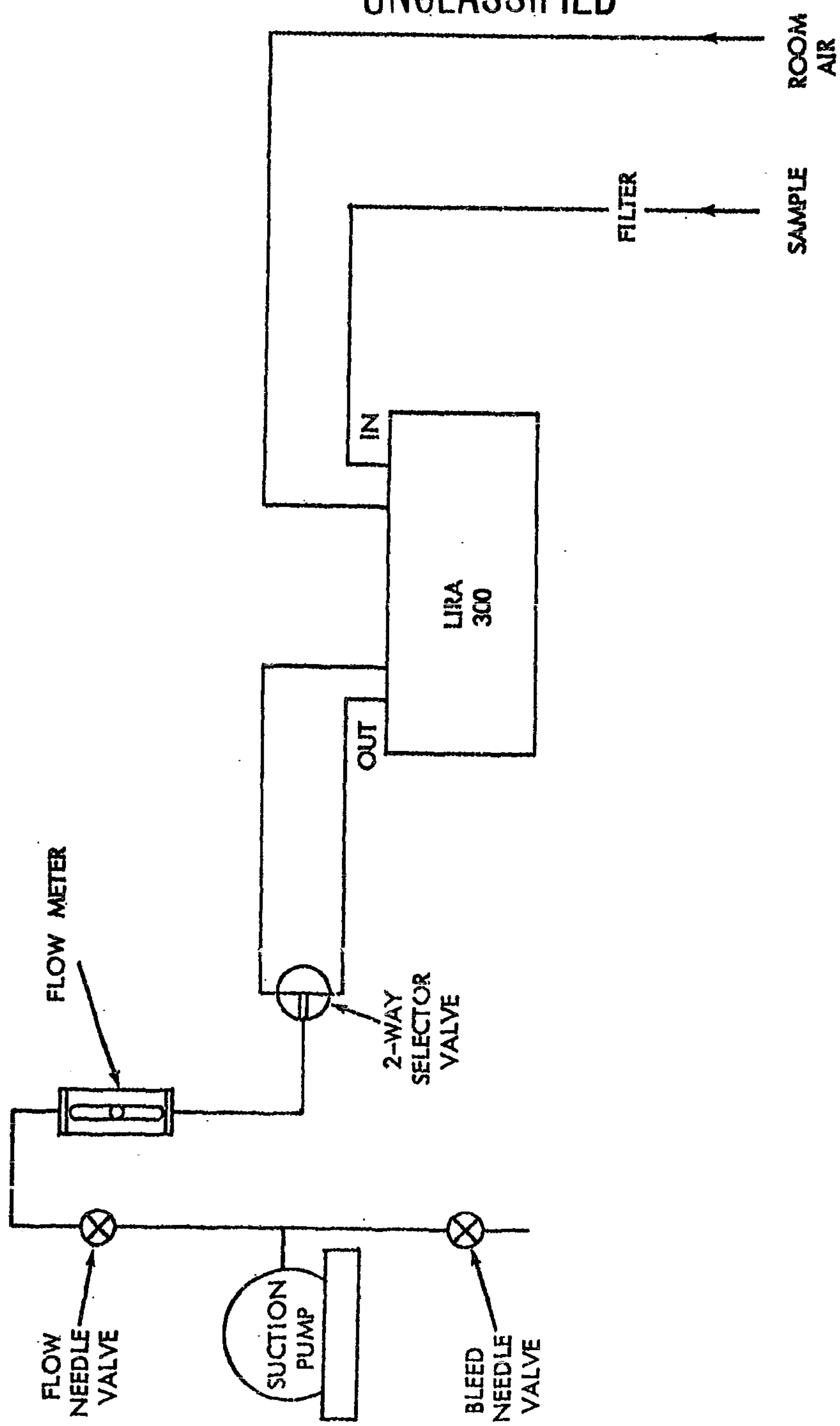


FIGURE 4
FLOW DIAGRAM FOR SHOT DETECTION

TABLE I

ESTABLISHMENT OF ZERO INITIATION LEVEL BY OPERATOR AND LIRA-300

DROP HEIGHT (CM)		TRIAL 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
80.0	OPERATOR	S																			
	LIRA-300	S																			
64.0	OPERATOR	S																			
	LIRA-300	S																			
51.2	OPERATOR	F	F	F	S																
	LIRA-300	F	F	F	S																
40.9	OPERATOR	F	F	F	F	F	F	S													
	LIRA-300	F	F	F	F	F	F	S													
32.7	OPERATOR	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
	LIRA-300	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F

Work carried out to dat ehas consisted of comparisons of the operator and Lira-300 in the following manner: (1) Shot-Failure distribution at the zero initiation level determined by the operator (Table II). This test provided a direct comparison of the operator and Lira-300 in distinguishing shots and failures at a given level. (2) Shot-Failure distribution in twenty trials run at the previously reported zero initiation level (Table III). This test provided a comparison of the results obtained by the operators, as well as the Lira-300 used in this investigation, with the results previously obtained by other operators. (3) Determination of zero initiation level. This test provided a comparison of the results which would be reported through use of Lira-300 and by the operator (Table IV).

It should be noted that since an absolute standard for the decomposition does not exist, it cannot be stated that the Lira-300 is actually determining the decomposition level. The selection of an absolute decomposition level would at best be arbitrary, since most materials decompose at some rate for a given set of conditions, and for all practical purposes, the rate will establish the "presence" of decomposition. This lack of an absolute standard does not however, invalidate the comparison of observations of the operators with the Lira-300.

DISCUSSION

Results obtained thus far show that agreement between the operator and Lira-300 is quite good. In the instances where differences occur, the Lira-300 appears to be the more sensitive, detecting shots which the operator does not observe. We see from Table II that the Lira-300 can detect shots that are not observed by the operator. This difference is apparent in the testing of materials wherein it is difficult to distinguish between shots and failures; e.g., nitrocellulose. Furthermore, from Table II it appears that there is little operator difference in ability to distinguish shots and failures. What difference does exist shows up in the results for "difficult" material.

This small difference in operators can be examined more closely in Table III where tests were conducted on four materials varying in the difficulty of detecting shots. The materials are listed in ascending order of difficulty with the casting powder considered easiest and nitrocellulose the most difficult. Here again we see that what operator difference exists comes to light when the more difficult materials are tested. It should be noted that for all tests where both the operator and Lira-300 detected shots, the shots detected by each occurred on the same trials, i.e., when the operator detected two shots in twenty trials, the Lira-300 detected the same two shots.

TABLE II

COMPARISON OF SHOTS AND FAILURES OBTAINED AT THE ZERO INITIATION LEVEL DETERMINED BY THE OPERATOR

SAMPLE	TEST 1				TEST 2				TEST 3			
	OPERATOR ONE ✱		LIRA 300		OPERATOR TWO ■		LIRA 300		OPERATOR THREE ▲		LIRA 300	
	S●	F○	S	F	S	F	S	F	S	F	S	F
COMPOSITE MODIFIED DOUBLE-BASE CASTING POWDER	0	20	0	20	0	20	0	20	0	20	0	20
NITROCELLULOSE	0	20	1	19	0	20	0	20	0	20	2	18

✱ OPERATOR THOROUGHLY TRAINED AND EXPERIENCED.
■ OPERATOR WITH INTERMEDIATE EXPERIENCE.
▲ INEXPERIENCED OPERATOR.
● SHOTS.
○ FAILURES.

TABLE III

COMPARISON OF SHOTS OBTAINED IN TWENTY TRIALS RUN AT A PREVIOUSLY ESTABLISHED ZERO INITIATION LEVEL

SAMPLE	TEST 1				TEST 2				TEST 3			
	OPERATOR ONE ✱		LIRA 300		OPERATOR TWO ■		LIRA 300		OPERATOR THREE ▲		LIRA 300	
	S●	F○	S	F	S	F	S	F	S	F	S	F
COMPOSITE MODIFIED DOUBLE-BASE CASTING POWDER	2	18	2	18	0	20	0	20	0	20	0	20
NITROGLYCERIN	0	20	0	20	0	20	0	20	0	20	0	20
DOUBLE-BASE PROPELLANT	0	20	0	20	0	20	1	19	0	20	0	20
NITROCELLULOSE	0	20	0	20	2	18	2	18	0	20	2	18

✱ OPERATOR THOROUGHLY TRAINED AND EXPERIENCED.
■ OPERATOR WITH INTERMEDIATE EXPERIENCE.
▲ INEXPERIENCED OPERATOR.
● SHOTS.
○ FAILURES.

TABLE IV

COMPARISON OF ZERO INITIATION LEVELS OBTAINED BY OPERATOR AND LIRA-300

SAMPLE	TEST 1		TEST 2		TEST 3	
	OPERATOR ONE ✱	LIRA 300	OPERATOR TWO ■	LIRA 300	OPERATOR THREE ▲	LIRA 300
COMPOSITE MODIFIED DOUBLE-BASE CASTING POWDER	32.7	32.7	40.9	40.9	40.9	40.9
NITROCELLULOSE	32.7	26.2	20.9	20.9	20.9	16.7

✱ OPERATOR THOROUGHLY TRAINED AND EXPERIENCED.

■ OPERATOR WITH INTERMEDIATE EXPERIENCE.

▲ INEXPERIENCED OPERATOR.

Table IV shows there is good agreement between the Lira-300 and operator with the Lira-300 obtaining the lower values. The operator-to-operator differences were considered reasonable in view of the differences in experience. Previous work has shown that at least one interval difference can be expected in zero initiation levels reported for different samples of the same explosive material using the same operator. These differences can be attributed for the most part to variability of the explosive material and the difficulty encountered by the operator in maintaining a constant impacted sample area.

Although not a part of this investigation it would appear the Lira-300 might be useful, not only in sensitivity research activities and routine sensitivity testing, but also as a safety device in the process area. The instrument might serve as a useful detector of combustion and as an initiator of protective devices.

CONCLUSIONS

From results obtained to date, the Lira-300 appears to be a useful tool for determining shots and failures for the decomposition level. It also appears to be more sensitive than the human being at low levels of initiation. The apparatus at this point appears to meet the basic requirements set forth for such a tool, with the possible exception of improving it's ability to detect lower concentrations of the decomposition products.

References

(1) R. C. Bowers, J. B. Romans & W. A. Zisman - NRL Report 5463 - "Mechanisms Involved in the Impact Sensitivity of RDX Explosive Compositions" - May 9, 1960.

(2) Conversation between R. H. Richardson - ABL and J. Wilby, ARDE-England at the Third Symposium on Detonation, Princeton University - September, 1960.

Col. Hamilton: At this point the agenda shows a presentation to be made by Dr. Shuey of Rohm & Haas. Dr. Shuey's commitments prevented his making this talk so we'll proceed to the next item. We'll be hearing from Rohm & Haas tomorrow on another subject. The next subject is 'Dividing Wall Tests' by Mr. Russel G. Perkins of the ASESB.

Mr. Perkins: Colonel Hamilton, Gentlemen: The presentation I am about to give may sound, at times, as if it does not apply too closely to solid propellant safety. However, in those cases where the propellant is detonable, it may be of immediate application and certainly where warheads and missile motors are together in the same space, the findings may, in many instances, be the same as for an equivalent weight of bombs or other high explosives.

As many of you know, for some years various authorities in the field have recognized the inadequacy of the state of our knowledge of the effectiveness of standard reinforced concrete dividing walls to prevent the propagation of a detonation from one mass of explosives to another.

This subject is of interest in manufacturing situations as well as storage. Historically, U. S. military planners have used 12" walls built of reinforced concrete to certain definite specifications as separation media to prevent propagation and/or especially simultaneous detonation. The purpose of this standard was to subdivide the total amount of explosives into smaller quantities so that the total did not have to be considered for protection of buildings from high explosive blast effects.

The normal limits established per cubicle or bay were 5000 pounds although in certain instances where operational conditions permitted limits of 2000 pounds or less were established and in some few instances it was necessary to accept the risk of amounts greater than 5000 pounds.

In January of 1959, Dr. Ralph Ilsley of the staff of the Armed Services Explosives Safety Board, made a detailed presentation to the Board outlining the inadequacies of the state of our knowledge of this subject.

Concurrently, the hazards attendant to the ever-increasing deployment of weapons and missiles in populated areas focused attention of the urgency of a comprehensive investigation of the subject. As one aspect of the problem, for example, with certain types of atomic weapons containing active material at all times, it is necessary to prevent propagation as well as simultaneous detonation in order to keep the release of this active material below allowable limits.

Recognizing that an area of doubt existed as to the ability of the one-foot walls to provide protection against propagation, the

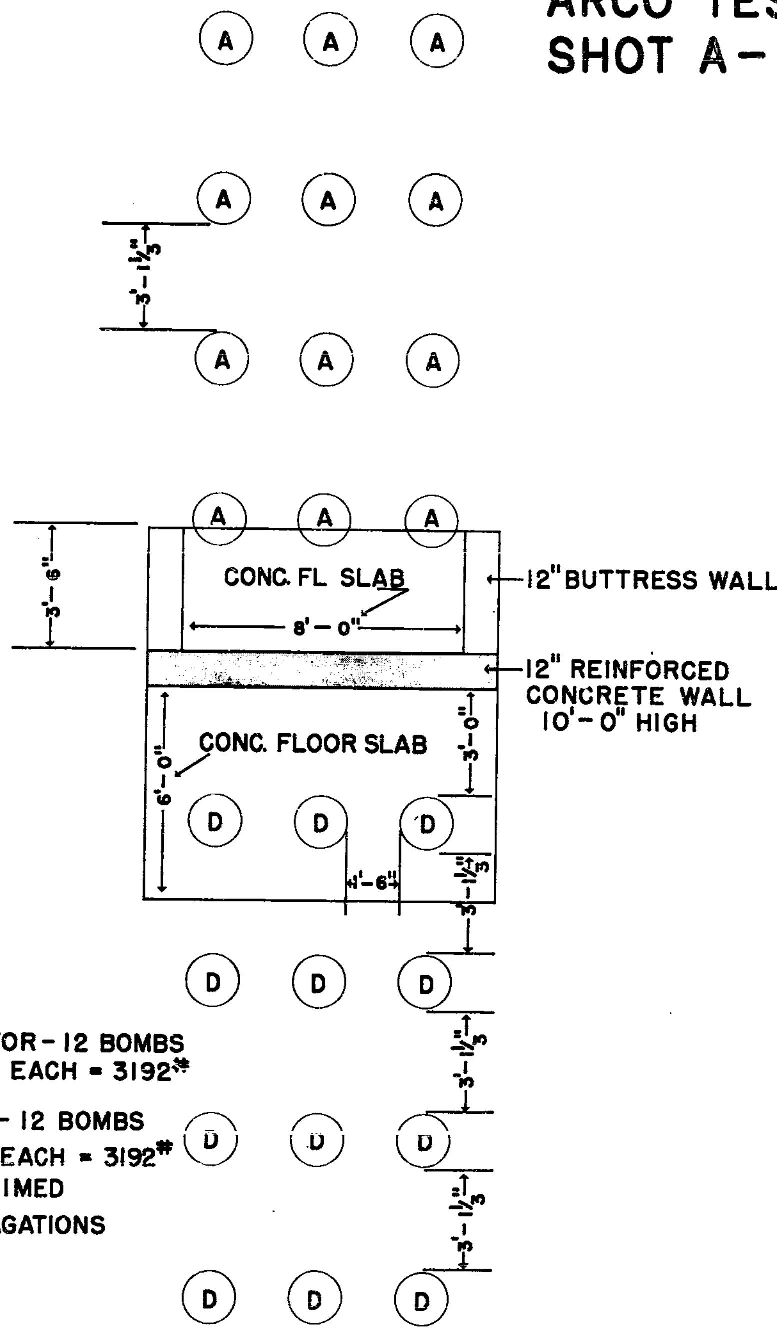
Chairman of the Armed Services Explosives Safety Board designated a work group to submit, from time-to-time for the Board's consideration, such recommended actions as the group determined might lead to solution of the various aspects of the problem.

We have embarked upon a series of test programs to determine, with more certainty, the ability of walls of varying thicknesses to prevent propagation and also to test other materials and configurations. I will describe some of the tests we performed and others of which we have knowledge. In 1944, U. S. military authorities were interested in the subject of propagation of explosions between masses of explosives on opposite sides of dividing walls and tests were made. The 1944 tests, however, were discontinued at a level that was too high to give the necessary data for most of our current problems.

The minimum weight of high explosives tested against the standard reinforced concrete wall in the 1944 tests was approximately 3190 pounds of TNT in GP bombs. This chart (Chart No. 1) describes the layout of the test, showing the disposition of the donor bombs which were in a dispersed arrangement rather than a concentrated charge and the layout of a similar arrangement of target bombs or acceptors. This test resulted in propagation to two of the acceptor charges. No further dividing wall tests were carried out until our present program which started in 1960.

The first of the modern tests performed simulated a set of conditions such as would be found in a manufacturing bay. The layout of the test is shown on this chart (Chart No. 2). This test was performed at an Army facility on 20 April 1960. The donor explosive totalled 1732 pounds of cyclotol in four spherical charges. There were eleven acceptor charges arranged as shown - they were approximately 100-pound spheres with differing case constructions and orientations. Detonation of the four donor charges was accomplished by detonating the outermost charge and 600 microseconds later, simultaneously detonating the other three. The delay was to simulate, as closely as possible, the interval of time that would occur from the time a detonation, started by the dropping or striking of a cased charge, propagated to other charges in the same bay. The minimum distance between any one of these three donors and the nearest wall was three feet. Each of the acceptor charges was located so that the high explosive charge was three feet from the outside of the wall and the different acceptor charge cases were positioned with different orientations so as to indicate differences, if any, occasioned by the presence of external hardware or other components, shipping cases, etc. Three of the eleven acceptor charges detonated. Two of these were light-cased and along the left-hand wall (the two center charges) and the left-hand heavy-cased item near the rear wall.

ARCO TEST SHOT A-4

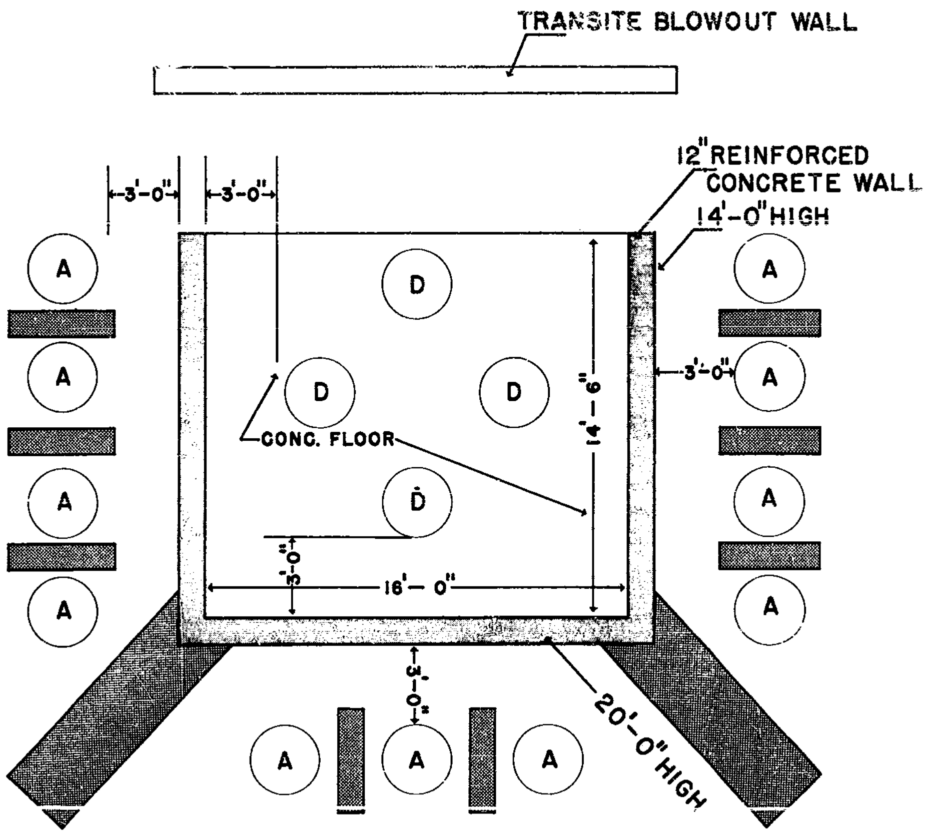


A – ACCEPTOR – 12 BOMBS
@ 266# EACH = 3192#

D – DONOR – 12 BOMBS
@ 266# EACH = 3192#
ALL PRIMED
2 PROPAGATIONS

Chart No. 1

PHASE B SHOT 1



A— ACCEPTOR CHARGES
D— DONOR CHARGES 431# H.E. EACH
— SAND BAG BARRICADES
3 PROPAGATIONS

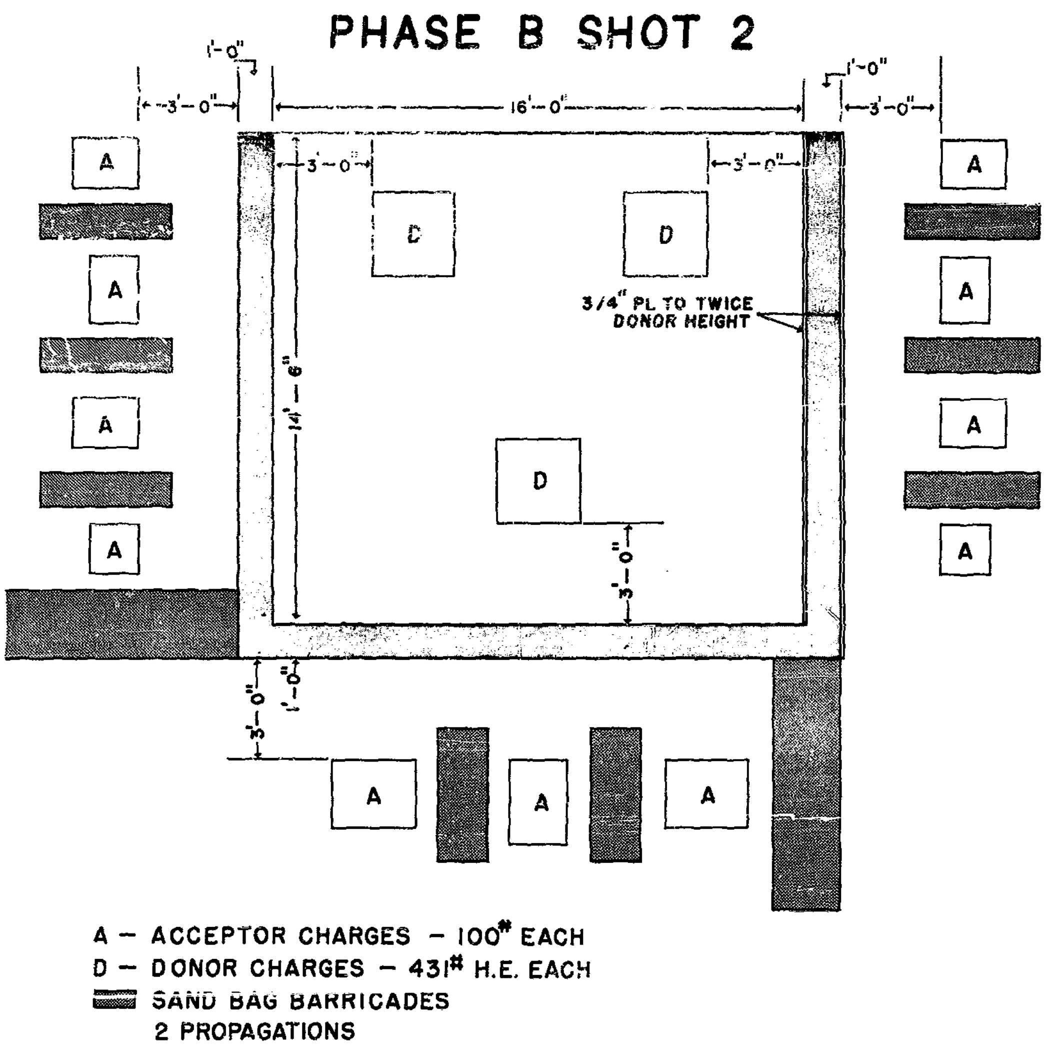
Chart No. 2

In view of the results of this test, it was decided that a retest of the manufacturing bay configuration, with several modifications, should be made (Chart No. 3). The donor amount was reduced to three charges totalling 1293 pounds of high explosive. The medium heavy-cased charges used previously on the right hand wall were omitted from the acceptor configuration in favor of additional light-cased items of the most vulnerable type currently in use. The rear wall was again used for the heavy cased weapons. In this test also there was a 600 microsecond delay between the detonation of the first donor and the other two. The right hand wall of the cubicle had 3/4 inch steel plates affixed to each face to a height of eight feet. The total height of the walls was approximately fourteen feet. This test resulted in propagation to the rear-most acceptor on the side with the steel plates and to the number three acceptor from the front along the other side wall. These three were not severely damaged; again, the heavy steel cases provided very good protection for the contained explosive charges.

I would now like you to see some films of this shot which show some good views of what takes place.

For ease of reference, we refer to the two recent shots just described as Phase B Numbers 1 and 2. Because of the failure to prevent propagation at a sufficiently high level, it appeared necessary to study ways of improving the situation in existing bays. An interested manufacturing plant then undertook a series of approximately fifteen small scale tests to study the value of various protective coatings which could be added to existing walls. They concluded that the most promising modification would be the addition of 6" of polyurethane foam plastic on each face of each wall. We are now planning a full scale test (Phase B No. 3) to gain further experimental data on the efficiency of this foam and to evaluate the effectiveness of small scale tests in evaluating the effect of explosives upon concrete walls. We hope that this test shot will be fired next week by NOTS.

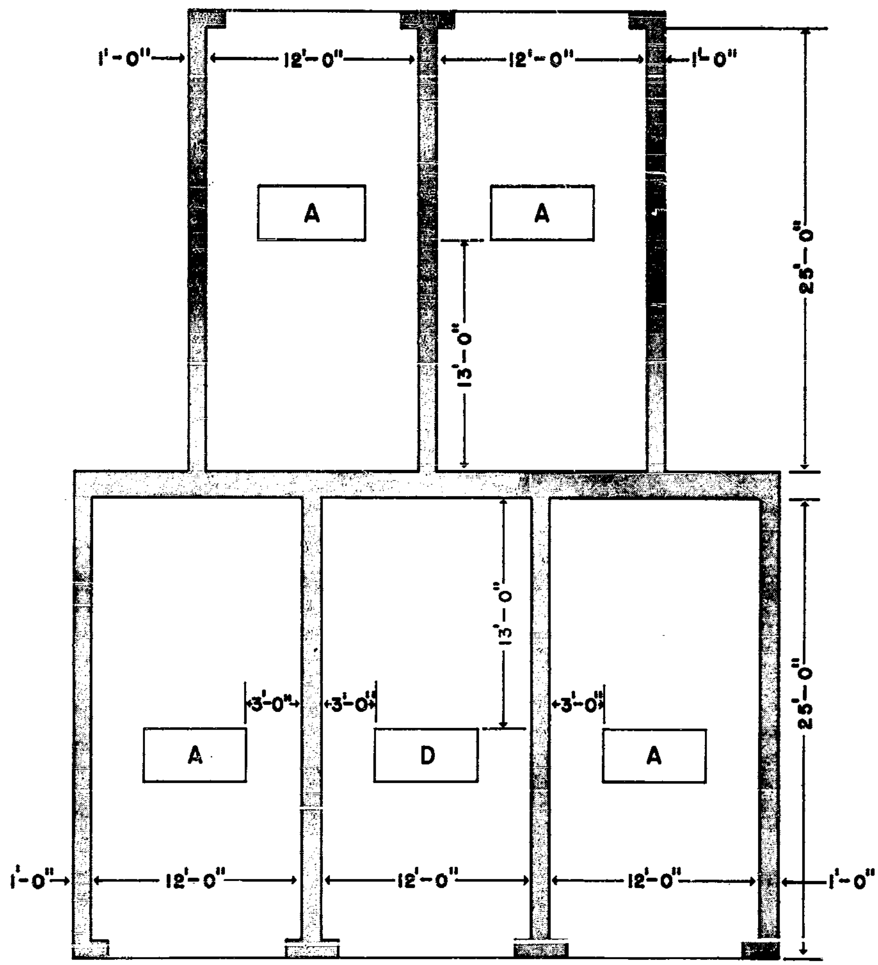
The second full scale test, in chronological order from the start of the program, was a test of a multi-cubicle storage structure (see Chart No. 4). This test was accomplished on 25 September 1960 at an Air Force test range near Salt Lake City, Utah. We refer to full scale simulations of Air Force operational storage as Phase A tests. The structure was built to simulate actual storage conditions. Each of five cubicles was loaded with four charges in a standard storage configuration on dollies. The center four charges on the side with three cubicles were intentionally detonated simultaneously. The total weight of donor explosive involved here is approximately 400 pounds. Each donor charge was contained within a steel case approximately $\frac{1}{2}$" in thickness. This test resulted in destruction of the side of the structure having three cubicles, but only breeching of



PHASE B SHOT 2
1'-0"
1'-0"
3'-0"
16'-0"
3'-0"
3'-0"
3'-0"
A
D
D
3/4" PL TO TWICE
DONOR HEIGHT
14'-6"
D
3'-0"
3'-0"
1'-0"
A
A
A
A — ACCEPTOR CHARGES — 100# EACH
D — DONOR CHARGES — 431# H.E. EACH
SAND BAG BARRICADES
2 PROPAGATIONS

Chart No. 3

PHASE A SHOT 1



A – ACCEPTOR CHARGE – 400# EA.
D – DONOR CHARGE – 400#

NO PROPAGATION

Chart No. 4

the 18" transverse dividing wall. The damage to the acceptors was not such as to indicate that there had been a "close call" with respect to propagation. The heavy cases of the charges apparently provide a high degree of protection against the type of impacts sustained. This has been borne out by other tests.

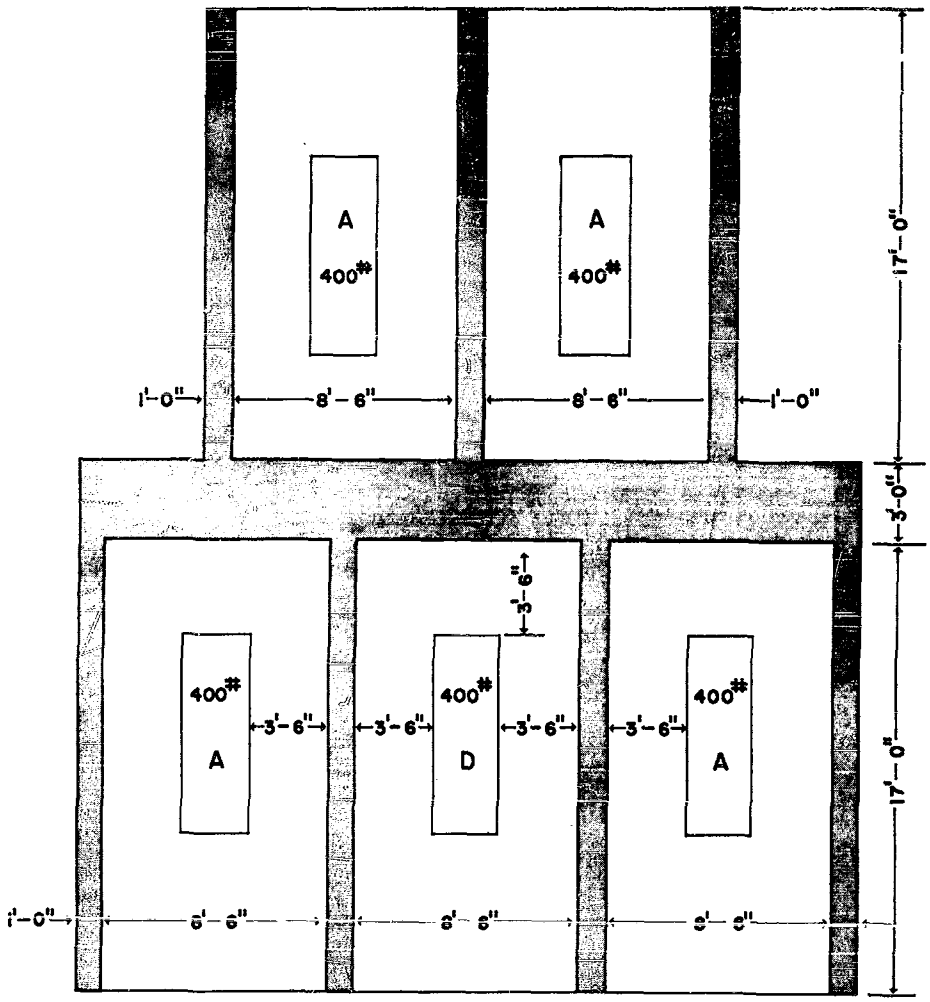
The same storage configuration was tested again using the same donor (400 pounds of cyclotol) but with a number of variations in the acceptor charges (Chart No. 5). Detonation of the donor in the primary cell resulted in propagation to only one of the three cells on this side of the wall and destruction of two of the acceptor charges located therein. These were virtually bare explosive charges and the chances of propagation were, therefore, maximized with respect to the weapon types that we are currently storing. The physical destruction of the cell was comparable to that which has occurred in the other tests with these and larger amounts.

A similar test of a multi-cubicle facility of different dimensions was performed (Chart No. 6). This is similar to the previously tested structure except that the transverse dividing wall is 3' thick. The donor charges had a total net explosive content of approximately 425 pounds. Of this, 325 pounds is a composite propellant and approximately 100 pounds is Composition B. The propellant was primed with approximately $7\frac{1}{2}$ pounds of Composition C4 to assure, as nearly as possible, complete detonation of all of the material in the bay. Again, this test resulted in destruction of the walls on the three-bay side, but there was no propagation to any of the acceptor charges. The acceptors in this case were the same as the donors except that C4 replaced the Comp. B.

In this test, the three-foot center wall was not damaged significantly. It was cracked through and there was approximately 6" deflection in the center of the span. The only damage to weapons on the other side of the wall was that occasioned by pieces of the roof structure being dislodged and falling upon them. We will now see some of the high-speed films of this test.

In order to obtain greater amounts of information at less cost per test, a series of shots using specially designed cubicles and acceptor charges so that the parameters of the tests could be varied, a greater degree than would be practicable when testing actual storage and manufacturing configurations was devised. We refer to this series as Phase C. Several of these tests have been performed. The first of these located two 500 pound GP bombs in a three-sided cubicle with 1' walls and distances of 2', 5', and 11'6" between the donor charge and the walls (Chart No. 7). Acceptor charges were discs of pentolite and Comp. B sandwiched between two sheets of aluminum and located 3' from the outside of the cubicle wall. This test did not result in

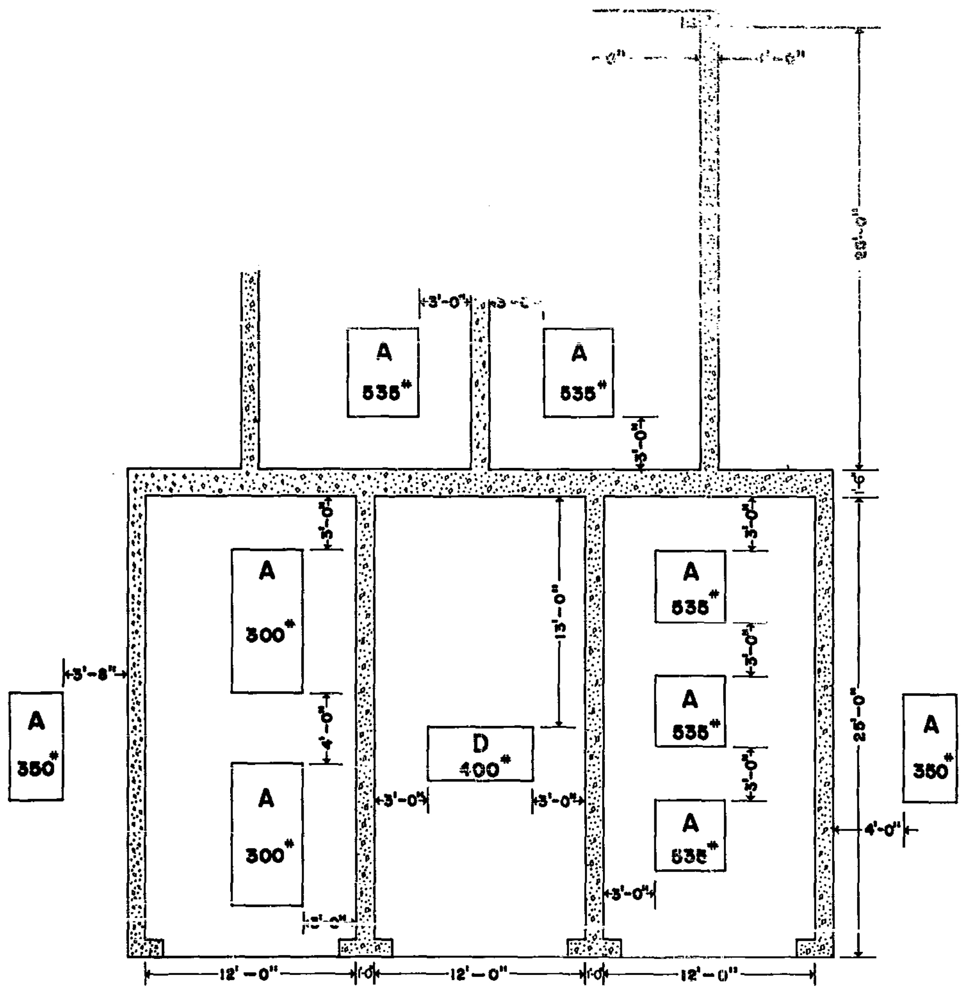
PHASE A SHOT 2



A – ACCEPTOR CHARGE – 400#
D – DONOR CHARGE – 400#   NO PROPAGATION

Chart No. 5

PHASE A SHOT 3

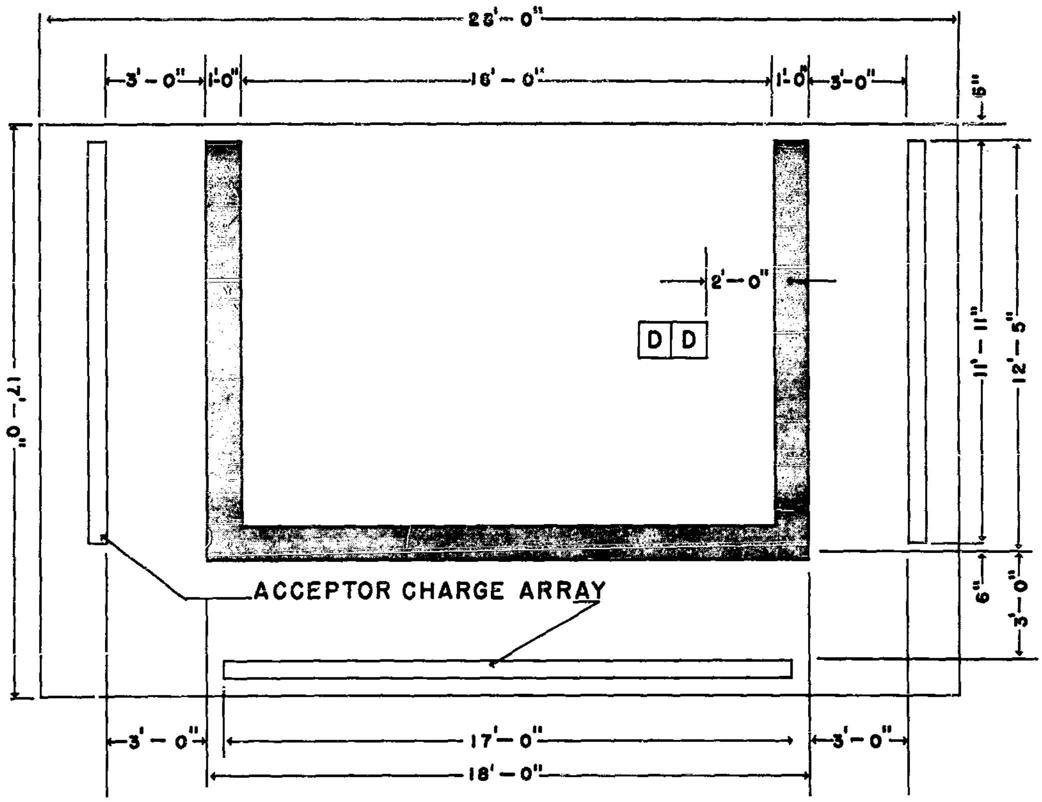


A – ACCEPTOR CHARGE
D – DONOR CHARGE

PROPAGATION TO 1 CELL
DESTROYED 2 CHARGES

Chart No. 6

PHASE C SHOT 1



D — DONOR CHARGE
2-AN-M64 A I GP 500#
BOMBS ON END — 544 LBS TOTAL. H. E.
NO PROPAGATION

Chart No. 7

propagation even though there was complete destruction of all three walls of the cubicle.

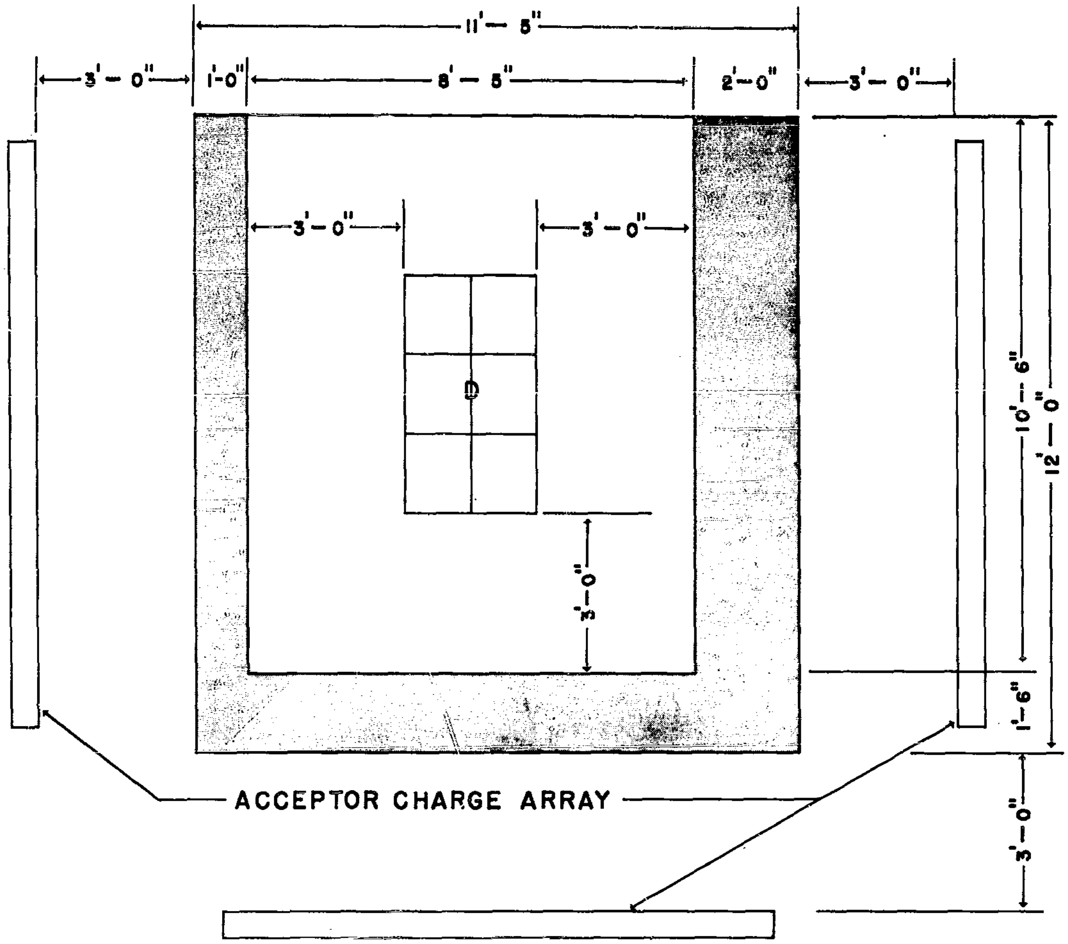
Phase C, Shot No. 2 consisted of six 500 pound GP bombs for a total of 1632 pounds of cyclotol, symmetrically arranged in a cubicle that had 1', $1\frac{1}{2}$', and 2' walls (Chart No. 8). The same type acceptor charges as in Phase C Shot No. 1 were used. This test, again, did not result in propagation although there was complete destruction of the three walls and mechanical destruction of the acceptor charges.

The third Phase C shot used an array of different acceptors (Chart No. 9). In this test, the acceptors were expected to provide a greater vulnerability than in the first two Phase C shots and, as you can see from the chart, the configuration of the donor charge was somewhat different from the previous Phase C tests. This shot gave one definite high order explosion from one of 56 acceptors, and six partials - low orders or other indications. The 56 acceptors represented four different levels of sensitivity as follows: special weapons detonators, PBX 9010, pentolite and Comp. B. The definite high order was a pentolite-loaded charge. The six partials were PBX 9010. Based upon this information, it seemed apparent that the specially-fabricated charges would not yield the amount and type of information for which we had hoped in cells with varying wall thicknesses and larger distances between the donors and the walls. In addition to inadequate definition of results, the specially fabricated acceptors were more expensive, more trouble to set up and interfered more with photography than simulated weapons which can be fabricated from reject and surplus parts which we get free from another program.

We then performed two tests in a cubicle of these dimensions (Chart No. 9) with the donors 2', 5', and 11'6" from the walls using light cased explosive spheres as acceptor charges, but only 2' from the wall rather than 3'. These two tests resulted in two detonations and one detonation respectively of acceptor charges positioned opposite the wall having the 2' separation from the donor.

To summarize briefly the results of these tests, although we have had propagation with an amount of donor explosive of 400 pounds to an almost bare acceptor, we have had no case of propagation with donor weights up to 1293 pounds in which the acceptor charges were inclosed in heavy steel cases. We feel that amounts larger than 400 pounds of high explosive could be accepted when separated by a 1' wall in those cases where case thickness, acceptor orientation, protective cover, sensitivity of acceptor explosives and the presence or absence of shipping containers are unfavorable to propagation. We have not had propagation through a wall greater than 12" in thickness. This includes four tests with up to 1500 pounds in the donor charge but the most vulnerable acceptors have not yet been used opposite the walls of greater thicknesses.

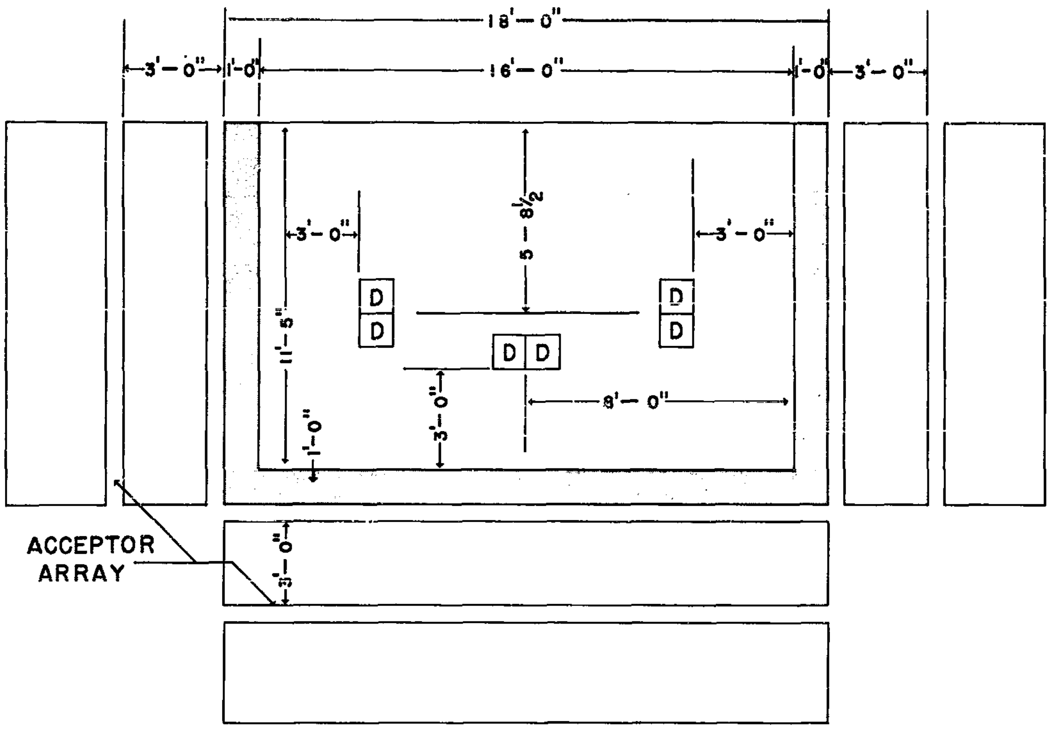
PHASE C SHOT 2



D — DONOR CHARGE
6 EACH 500 LB GP
BOMBS — AN - M - 64 A1
COMP. B LOADED - 1632# TOTAL H. E.
NO PROPAGATION

Chart No. 8

PHASE C SHOT 3



D — DONOR CHARGES
AN — M — 64A1 G.P. 500# BOMBS
@ 272# H.E EACH — TOTAL 1632# H. E.
1 PROPAGATION

Chart No. 9

In the situations in which we are concerned, considerable protection can be provided by weapon cases and shipping containers and there is a possibility of adding other protection such as padding or increasing the strength of shipping containers.

The most likely cause of the initiation of the acceptor charges appears to be the impact of large, relatively slow-moving fragments of concrete against the acceptor. We have considerable evidence that, for larger amounts of explosives, the reinforced concrete construction may actually be a poor separation medium, but we also have not had any detonations occurring from propagation through walls of greater thickness than 1'. It appears that, for amounts of 400 pounds or less, we are in relatively good shape.

We intend to continue this testing and investigation with small scale and model tests to yield more information about the specific mechanism of initiation and to test additional barriers such as treatment that could be added to existing walls; and other types of storage such as small earth covered igloos for the storage of individual charge or small numbers of charges.

Recently, in the Phase C program, we completed two tests each involving a single 500 pound GP bomb (274 pounds of Comp. B) as a donor and the spherical acceptor charges. No propagation occurred although the walls were seriously broken up. We intend to continue this full scale testing to determine a threshold limit of safety for amounts of high explosives with walls up to 3' in thickness. These tests should also provide more information with respect to the importance of protection afforded by different types of charge cases, different sensitivities of explosives, etc.

Mr. Higgins: We've recently built a plant out in Mesa, Arizona. I noticed in the first firings, you didn't have a roof on this facility that you had. Don't you think that had a great deal to do with the detonation of your charges around the sides and to the back. I noticed it seemed like the shock wave came over the back and over the sides.

Mr. Perkins: Consider this as my opinion. You can take it as you will. I don't personally feel that the roof and rear walls make any difference. I don't think they are a factor in the propagations that we have had. There is a great deal of professional disagreement on this subject and we have not yet adequate information from either the literature or the tests that we have run to answer your question.

Dr. Noonan: You said something rather quick about a new test with polyurethane foam or polystyrene foam or something, 6" of foam on either side of the wall. What are you going to do with this now?

Mr. Perkins: This will be a three sided cubicle similar to those that you saw in the pictures with 6" of polyurethane foamed plastic on each face of each wall completely covering the entire cubicle. Otherwise the test conditions will be similar to the Phase B No. 2 which had three donor charges totaling 1293 pounds of HE, the one that had the steel plates on it. It will be configured similar to that test but with the foam added to the concrete wall.

Dr. Noonan: I would rather think there wouldn't be much difference because the foam is mostly air and it's not going to stop any shrapnel. You need something that the momentum can be transferred to - water or sand or something.

Mr. Perkins: The foam treatment was recommended as a result of a series of small scale tests by one of the ordnance facilities and it appeared as a result of those tests to show some promise in this area.

Mr. Norman Hirsch, Edwards AFB: In one of your tests I believe you used a test item, a rocket motor weighing approximately 320 pounds. Is this right?

Mr. Perkins: Yes, this is correct.

Mr. Hirsch: Could you identify this rocket motor?

Mr. Perkins: It's an MB1.

Mr. Hirsch: Okay, then in regard to this test, you said you had a detonation of this rocket motor?

Mr. Perkins: I didn't say anything about what happened to the rocket motor. I said that the concrete walls of the cell were broken up in a manner equivalent to that which was done by 400 pounds of cyclotol in a preceding test.

Mr. Hirsch: The thing that bothered us, we ran tests at Edwards on this same rocket motor and we carried our donor up to around 25 pounds TNT and also a few years ago at Ogden they ran tests on the MB1 and our tests at Edwards showed a maximum support of about 20%, so based on this I don't see how you can assume 400 pounds donor for your tests on these walls.

Mr. Perkins: I merely repeat, I didn't assume anything. I just looked at the damage done to the cubicles after the test was completed. It is not really of serious concern to me what the yield was except that the only measure we have of the yield from this weapon, was the mechanical damage done to the structure. And it was quite comparable to that done by four 100 pound Comp. B charges.

Col. Peter: My first question is, did the walls have interlocking reinforcement around the corners and secondly, have tests ever been run without interlocking reinforcement around the corners?

Mr. Perkins: The specifications for the structures are the same as those for building ordnance type protective construction. The reinforcing steel is supposed to be of the amount and type and placed in the same way as it would be in your manufacturing buildings. One of the tests was an unused WWII manufacturing building which after the test was found not to have had the steel implaced in exactly the standard manner. In some other cases, the steel reinforcing had not been interlocked as you term it in just the way we might think best. However, up to now the results of our tests haven't indicated that the placing of the reinforcing steel was an important factor in the results that we got on these tests. We plan to vary the amount of the reinforcing steel and possibly the placing of it as the test program progresses.

Mr. R. G. Keim, Aerojet-General Corp.: Your film clearly illustrates the severity of the damage to construction aboveground. I was just wondering if you had ever given any consideration or do you have any statistics on damage below ground level? What I mean by that is your, for instance, domestic system, your fire water service, your electrical conduit systems and perhaps the foundation for overhead tanks, etc. I was just wondering what your ground movement might be from a detonation of the severest type. Do you have any information on that at all?

Mr. Perkins: Of course, we're not investigating this particular subject with this series of tests. However, we have not any information from it that indicates there is a particular problem in the area that you mentioned. This associated with other effects of accidental explosions and certain other tests indicates that -

Mr. Keim: My reason for asking was simply that in storage areas where you may have such missiles stored, it may be the determining point, or the factor in determining where your storage area will be with reference to aboveground construction.

Mr. Perkins: I don't believe that this subject really is related to the one that I have been discussing. Yes, you can damage the underground utilities by explosion if you don't properly place the storage but this is just the normal quantity-distance question that you would have for protection of other things from the explosions.

Mr. Jezek: Didn't we use other material besides foam on these walls? I thought we used some rope mats and all that sort of thing, perhaps they'd be interested in knowing about that.

Mr. Perkins: The model tests did include various treatments, blasting mats, different types of foam, sand and fibreglass impregnated plastic, I don't have a complete list of the substances tried, but in this series of 15 small scale tests the foam appeared to the operators of those tests to provide the greatest promise, although we all admit that we don't have a very big statistical basis for this recommendation.

Mr. Saffian: This is relative to the comment made by the gentleman from Edwards AFB. In our discussions of the Utah tests, one of the reasons we tossed around for the apparent 100% contribution of propellant was the particular configuration of the donors and the possibility of a directional effect there which may have masked any differences in composition. This may be one reason for that. I don't know what the configuration was in these earlier tests that were referred to.

Mr. Perkins: This is true enough, there are unanswered theoretical questions in connection with that but the purpose of this series of tests is to determine the effect on the dividing walls and the hazard of possible propagation.

Mr. Howard T. Scott, Atlantic Research Corp.: I'd like to know if you've considered your test results in relation to the publication by the Corps of Engineers of 1946 relative to protective design? Have you had a chance to review the charts and information contained in that report in the light of your tests?

Mr. Perkins: One of the people who has worked most closely with me on this subject since it started is the head of the Protective Construction Branch of the Office of the Chief of Engineers and I think that we have probably given adequate consideration to this publication.

Mr. E. M. Fisher, BuWeps: I'd like to comment on the question the gentleman asked previously on the damage to nearby underground structures. I'd like to say that the ground is a very good absorber of the explosion energy and that two or three crater radii away underground structures will not be severely mangled and that propagation to items that are stored this far away will generally be safe.

Col. Hamilton: The effects of the type of soil, the type of underground strata that you have will have quite an effect. Sometimes you will have quite a bit of shock transmitted, other times it will be almost entirely absorbed, it depends a great deal upon the type of underground structure that you have.

Mr. M. Naron, Thiokol Chemical Corp.: I have two questions actually. One is, in your program, do you anticipate testing anything in the nature of steel dividing walls rather than concrete dividing walls?

Mr. Perkins: The contemplated test program includes the investigation of other separation media which might be used than reinforced concrete. We don't know exactly how far we will go along this line or what we may suggest using.

Mr. Naron: Do you have any notion of using shaped cubicles other than the normal cube or rectangular shape?

Mr. Perkins: We have discussed the possible effects of other shapes - such things as fillets in the corners to remove the rectangular shape. We haven't gotten far enough with our investigation to know exactly where we might go in this regard either.

Mr. Endsley: With respect to the question on the percentage of contribution that might emit from the M81 motor, we have had impact tests which have given us confidence that we can get 100% contribution from this motor, and this cubicle test only further validated this basic assumption that had been made on previous tests. There have been some tests that we got contribution, but we know that we have had situations where they had 100% contributions. We feel we have a high confidence of getting this energy level out of the motor in certain situations. The next question about design, as soon as we get some of the answers on materials, techniques and procedures taking into consideration the cost factors, I know that the Civil Engineering type people - particularly in the Air Force - are very anxious to get ahold of some of the answers in order to start design on a protective type structure. We have been discussing this very freely and feel that we don't have all the answers in walls, we don't have all the answers in roof, venting construction, doors and things of this nature. We need many of these type of things in the current high energy propellant and explosives that we are dealing with in our current weapons systems. So we have a very fertile area of exploration ahead of us in the next few years. This is our personal opinion at the moment.

Mr. K. R. Broom, Aerojet-General Corp.: I'd like to ask if any blast pressure measurements were made during these tests that would indicate whether the receptor charges added to the blast pressure that might have been expected from the donor charges?

Mr. Perkins: I think I understand what you're getting at. The results of the tests to date have definitely indicated that we are not on firm ground in some of the decisions that we have made as far as reducing required distances because of the presence of the dividing wall. We are making blast pressure measurements around these tests so that we will have information with which to study the question you raised. However, in most the relative size of the donor and acceptor on these tests has been such that we wouldn't get the kind of information that I think you're speaking of.

Mr. Scott: I'd like to rephrase my question of a few minutes ago. Did your tests indicate that protective design based on the Corps of Engineers report may be inadequate?

Mr. Perkins: Our tests indicate that protective construction with explosive limits per cubicle in the vicinity of 2 to 5,000 pounds of HE are not adequate. The only thing that we have investigated in this program so far is the prevention of propagation of an explosive incident from one mass to another when separated by an intervening dividing wall. We know that the standards formerly applied in this regard are not adequate and we are now trying to establish adequate standards for this purpose.

Col. Hamilton: I'd like to throw in a remark here. The problem now is quite different than it was years ago. At that time we were primarily concerned with preventing simultaneous detonations so close together that the pressure peaks were superimposed on each other so that you had the effect of the total mass going at one time. Now, with the new types of weapons, we are very much concerned with actually preventing propagation from one item to the other without regard to the time limit.

Mr. Hirsch: In regard to this MB1 rocket motor, I would now like to disregard the effect of the wall and just talk about the rocket motor itself. We have heard comments now saying that this can go 100% support and I believe right now this MB1 rocket motor is being handled as a Class 2 item. If this is true, maybe this should be changed to Class 10.

Mr. Perkins: I would like to comment on that to the effect that again we are seeking information about propagation through the walls. The dividing wall tests are not hazard classification tests. The interest that we have is what the weapons will do in a cubicle under certain test conditions. We admit that these test conditions may not necessarily be those which you would be most likely to find in practice, but with regard to that particular item, I don't think anybody has raised any question about the classification of a whole unit, the warhead and motor together in storage as Class 10. If they have, this is news to me and I would consider it grievously in error. When the warhead is attached to the motor and the material is in storage it is all Class 10 as far as I'm concerned and I thought it was to everyone else.

Mr. H. M. Roylance, BuWeps: With regard to the design features which we were discussing a little while ago, we have found it necessary to design walls before we can wait for the results of these tests and our newer designs have incorporated a sandwich type of construction with 6" of concrete as the bread as it were

and about a foot of sand in between. We are anticipating that this will prevent propagation with quantities in the neighborhood of 1000 pounds. We are also faced with the problem of providing the protective wall for check-out instrument panels and for people. We are going to considerably thicker walls in the neighborhood of 5' for these plus some separating distance, maybe 30 or 40' filled with earth and this sort of thing. But I think the extension of these tests are going to have to envision personnel protection too in the future. So I think we're going to have to, after we worry about propagation, start worrying about people.

Mr. Perkins: We have, as he has indicated, a field wide open for investigation of many things that we don't know enough about. Up to now, however, the propagation problem has been the most critically urgent and information that we get with respect to personnel protection and equipment protection is secondary but we are trying to get as much as we can out of each test.

Mr. H. D. Mytinger, OOAMA, Hill AFB: Now is as good a time as any to settle this MB1 question. The motor itself is properly classified as Class 2. The assembled weapon is Class 10. This has been substantiated by a number of tests with no guesswork about it.

Col. Hamilton: Thank you very much Mr. Perkins. Our next item is 'A Philosophy of Protective Wall Design' by Mr. L. W. Saffian.

Mr. L. W. Saffian, Picatinny Arsenal: Generally, in considering any actual explosives manufacturing and/or storage situation of interest to Ordnance, the design or capacity of a protective wall or combination of walls (i.e. a manufacturing bay or storage cubicle) must be determined. Although the Ordnance Safety Manual gives guide lines for the establishment of barricades and substantial dividing walls which have been used effectively for many years, a detailed, quantitative procedure for assessing the degree of protection which may be expected from existing protective walls, or designing new walls is not currently available. Furthermore, although a substantial amount of work has been done in the development of protective wall design criteria, based upon existing data and theoretical considerations, this work has been primarily concerned with relatively distant effects of explosions where a plane wave approach may be employed. Although situations of this sort are occasionally of interest to Ordnance, the majority of actual cases are concerned with close-in effects where explosives are in relatively close proximity to the protective wall. Because of the non-uniformity of wall loading in such cases, application of the plane wave theory is not valid.

Recognizing, some time ago, the need for the development of more quantitative and more precise safety design criteria, Picatinny Arsenal

initiated a broad program, one of the ultimate objectives of which was the establishment of structural design criteria for protective walls. Our studies in this area (being accomplished with the contractual aid of the firm of Ammann and Whitney, New York, N. Y.) are now nearing completion. I would like to give you a general picture of the design approach, after which Mr. R. Rindner will discuss some specific applications.

In simplest terms, a typical explosive system for which structural design criteria must be considered consists of a donor explosive charge (e.g. weapon, processing vessel), which produces the damaging output, an acceptor (e.g. another explosive charge, personnel, equipment), the sensitivity of which determines what degree of output it can tolerate and the intervening protective walls, barricades, and/or distances which must reduce the donor output to a tolerable level with respect to the acceptor. It is essential to note here that, since in most cases of donor detonation, the protective wall will be damaged at least to some extent, major consideration must be given to the output resulting from wall breakup (e.g. concrete missiles). The overall design approach, therefore, was divided into three separate, but related areas, namely, donor effects, wall responses, and acceptor effects.

Let us first briefly consider the donor charge, which determines the blast loads and primary fragments (i.e. fragments resulting from breakup of the donor casing) acting on the protective wall. Here, we must calculate the pressure and impulse patterns formed on the wall surface as a function of donor characteristics (e.g. equivalent weight, casing, output) and distance from the wall. Also, mass-velocity characteristics of the primary fragments must be determined. Procedures for calculating equivalent weight of any donor charge and primary fragment characteristics were presented at previous Explosive Safety Seminars and are covered in detail in Picatinny Arsenal Technical Reports DB-TR: 1-59 and DB-TR: 6-59.

We come now to consideration of wall responses which is the most complex phase of the design procedure. The major portion involves analysis of response of the protective wall to the blast loads resulting from the donor explosion. These loads are expressed in terms of four modes of failure which may impair the structural integrity of the wall. These are as follows:

1. Spalling of the rear surface of the wall causing formation of secondary missiles.

2. Local failure in which excessive shear stresses cause punching out of a wall section, which may in turn break up into several smaller missiles.

3. Flexural failure caused by overall flexing action which brings the wall to the point of incipient breakup.

4. Total destruction of the wall causing complete breakup into secondary missiles.

In addition, the wall may be subjected to the impact of primary missiles resulting from the fragmentation of any casing surrounding the donor charge. This may result in primary missile penetration and/or spalling.

In any specific design problem, each of the various modes of possible wall failure are considered in a stepwise calculation procedure which indicates the relative importance of the different modes, and establishes the specific design criteria (i.e. wall dimensions, degree of reinforcement). In our studies to date, free standing (cantilever) walls and further restrained (e.g. storage cubicle) walls have been considered, as well as three basic types of wall construction, namely:

1. Standard reinforced concrete wall (tension reinforcement).

2. Standard reinforced concrete wall with stirrups added (shear reinforcement primarily to prevent punching).

3. Sandwich wall (two concrete walls with sand fill between them)

In a given situation, the importance or, for that matter, the occurrence of any one mode of failure is dependent upon the resistance of the particular wall to the particular mechanism involved, and the size of donor charge and its location with respect to the wall. Quite often one or two of the possible modes of failure may take place without occurrence of the other modes. For example, if a small donor charge is placed close to a wall, a relatively small area of the wall normal to the charge is affected, and only partial destruction takes place due to spalling and/or punching. On the other hand, if a large donor charge is located at the same scaled distance from the wall as the small charge, total destruction of the wall may occur immediately following spalling and/or punching due to its flexural instability under these conditions. Another example is the case of a large charge located at a relatively great distance from the protective wall. Here, if failure occurs it will probably be due to total collapse of the wall resulting from flexural distortions, without occurrence of spalling or punching.

Let us now consider the third major consideration in our design approach, the acceptor. Our primary interest here lies in the sensitivity of the acceptor to the various outputs, i.e. blast,

primary missiles, and secondary concrete missiles. For each type of output, the threshold conditions at which intolerable effects on the acceptor are first produced, must be determined. In this regard, two basic degrees of protection are considered, namely, (1) total protection whereby virtually no damage is permitted in order to protect personnel and/or costly equipment, and (2) a lesser degree of protection whereby damage, or even destruction, of a protective structure is tolerable provided that donor output effects are reduced to, and output effects resulting from breakup of the protective structure are held to a point where propagation of explosion to the acceptor charge does not occur. Methods for determining threshold conditions for prevention of explosion propagation due to blast and primary fragment effects were developed in earlier phases of our overall program and were presented, in general terms, at the two previous Explosives Safety Seminars. These methods are covered in detail in Picatinny Arsenal Technical Reports DB-TR: 1-59, DB-TR: 6-59, and DB-TR: 6-60.

I would now like to present Mr. Richard Rindner, whose paper will cover examples of four basic applications of the design techniques.

Col. Hamilton: We will have the question period on this after Mr. Rindner makes his presentation and you both can take on the questions together.

Mr. R. M. Rindner, Picatinny Arsenal: This presentation 'Applications of Proposed Protective Wall Design Techniques' deals with solutions of some basic problems encountered in the design of a barricade and/or substantial dividing wall to prevent explosion propagation and to provide personnel protection from blast and missile impact caused by an explosion. Four specific cases will be considered in this paper:

Case 1. Design of a new cantilever (free standing) wall to prevent propagation of detonation.

Case 2. Investigation of an existing cantilever wall to prevent propagation.

Case 3. Design of a new restrained wall to provide total protection (for personnel and specialized equipment).

Case 4. Investigstion of an existing restrained wall to provide total protection.

These solutions are accomplished using the design principles and criteria described in Mr. Saffian's presentation. Let us first consider the case where a new structure is to be erected to prevent propagation.

Case 1:

Slide 1 shows the conditions assumed for this example.

1. Cased donor charge equivalent to 500 lbs of spherical bare TNT.

2. Distance between the charge and the wall = 3 ft., corresponding to reduced distance Z = 0.5. The charge is located 3 ft. from the floor.

3. The striking velocity of primary fragments on the wall = 5,000 ft/sec. (calculated according to the procedure outlined at the first Explosives Safety Seminar and contained in Ref. 1). It should be mentioned at this point that the initial velocity is conservatively assumed to be equal to the striking velocity of primary fragments because of the close proximity of the charge to the wall.

4. The mass of the largest primary fragment produced by the donor explosion (calculated according to the procedure outlined in Ref. 1) = 2 oz.

5. Sensitivity of acceptor to:

a. Pressure leakage around and over the wall = 100 psi. This pressure corresponds to a blast sensitivity constant value, K = 3.1 (determined to be a conservative figure as a result of work done in an earlier phase of the Picatinny program discussed at the first seminar and described in Ref. 2).

b. Primary missile impact. Assuming acceptor casing thickness to be equal to 0.2 in., the boundary velocity (fragment velocity which will cause acceptor detonation) is found from Ref. 1 to be = 2000 ft/sec.

c. Secondary concrete fragments. These result from punching, spalling and/or complete wall destruction and must be known in terms of fragment masses and their velocities. As of this date no reliable data are available in this area and a program is underway to obtain such information experimentally. The importance of this program can not be overestimated in view of the fact that large scale tests on propagation through protective walls have indicated that the most probable cause for propagation of detonation is secondary missiles.

Based upon the conditions given in Slide 1 the procedure for the design of a new wall is divided into two main portions, namely, design for primary missiles and design for blast over-pressure. The first portion investigates the effects of primary missile impact. Here, the wall thickness is first obtained to prevent propagation due to missile perforation (full penetration) of the wall.

SLIDE 1

DESIGN OF A NEW STRUCTURE TO PREVENT PROPAGATION

GIVEN

1. CHARGE WEIGHT = 500 # OF TNT CONTAINED IN STEEL CASING
2. DISTANCE = 3.0' FROM THE WALL CORRESPONDING TO SCALED DISTANCE OF 0.5
3. SIZE OF LARGEST PRIMARY FRAGMENT (m_1) = 2 OZ
4. VELOCITY OF PRIMARY FRAGMENT (V_1) = 5,000 FT/SEC
5. SENSITIVITY OF THE ACCEPTOR (COMP B) TO:
   a. ALLOWABLE PRESSURE LEAKAGE =100 psi
   b. PRIMARY FRAGMENT IMPACT (ASSUMING ACCEPTOR CASING = 0.2 IN) = 2,000 FT/SEC
   c. SECONDARY MISSILES (RESULTING FROM PUNCHING AND TOTAL DESTRUCTION)

Slide 2 relates the ratio of residual velocity to striking velocity (V_2/V_1) to the ratio of wall thickness to maximum penetration (T/Xm). Since V_2/V_1 is equal to $\frac{2000}{5000} = 0.4$, we find T/Xm on this graph to be 0.82.

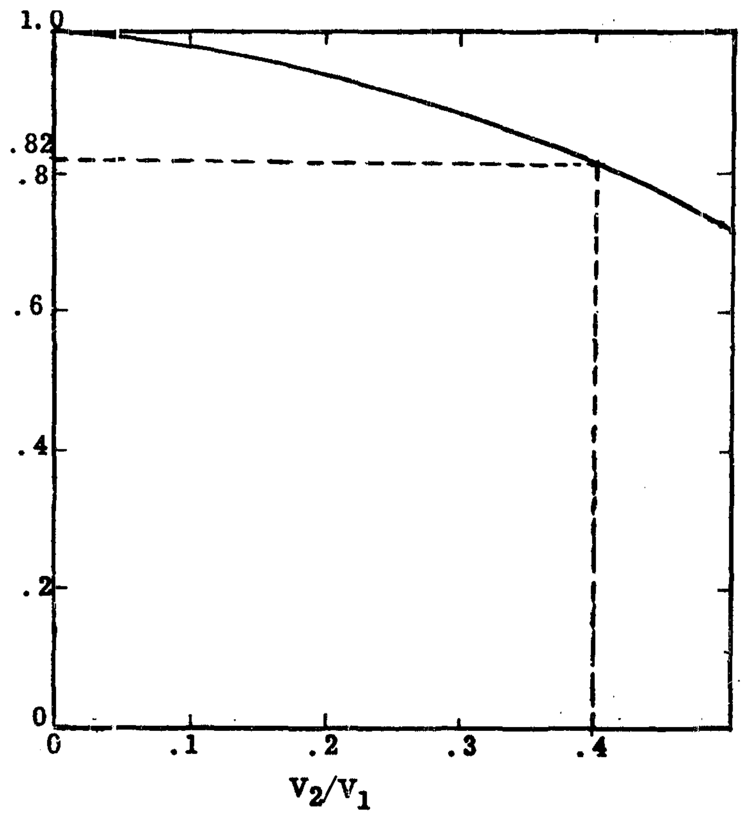
Slide 3 relating the striking velocity of the primary fragment (V_1) to maximum penetration (Xm) shows that for a fragment size of 2 oz. Xm equals 10 inches. Therefore, the wall thickness required for primary missile protection against propagation equals .82 x 10 = 8.2 inches. (If the wall thickness were 10 inches then the residual velocity of the missile would be zero). When the sensitivity of the acceptor can tolerate perforation, then spalling due to primary missile impact need not be investigated. This is the case in our illustrative example.

Once the thickness for primary missile protection has been established, blast overpressure is considered. First the wall thickness is established for punching failure which will produce secondary missiles, the mass-velocity characteristics (e.g. kinetic energy) of which will have to be less than that required to cause propagation. Because, as I mentionedaat the start of this presentation, there is no reliable information as to threshold energy requirements to cause detonation in the acceptor by impact of concrete missiles, certain assumptions will have to be made.

Let us assume, very roughly, that the minimum kinetic energy necessary to cause propagation by secondary missiles in the range of the velocities and masses calculated in our illustrative example is equal to 1,000,000 ft.-lbs. Slide 4 relating donor charge weight (We) with the velocity, mass and kinetic energy of the punched out fragment for a 1 foot thick concrete wall shows that for a 500 lbs charge at a reduced distance of Z = 0.5, the kinetic energy of the secondary missile, initially broken away from the wall, having a mass of 105 lbs.-sec^2/ft. and a velocity of 225 ft/sec., is equal to 2,600,000 ft.-lbs. This assumes that the punched out fragment emerges from the wall as a single piece. The possibility of this fragment being broken into several smaller, higher velocity fragments will be discussed later in this paper. This calculation indicates that the energy of the punched out fragment in this mass-velocity range will cause a high order detonation in the acceptor charge if donor and acceptor are separated by a 12 inch standard reinforced concrete wall. Three possible alternatives may be considered to increase the safety of this explosive system. We can either, (1) introduce stirrups (shear reinforcement) into the 12 inch wall, (2) increase the wall thickness, or (3) build a sandwiched wall consisting of two concrete walls with sand between them having the proper protection characteristics. First let us consider reinforcing the standard wall by introducing stirrups. If this is done, the

SLIDE 2

RATIO OF RESIDUAL VELOCITY TO STRIKING VELOCITY VS RATIO OF WALL THICKNESS TO FRAGMENT MAXIMUM PENETRATION



V_1 - STRIKING VELOCITY OF PRIMARY FRAGMENTS (FPS)

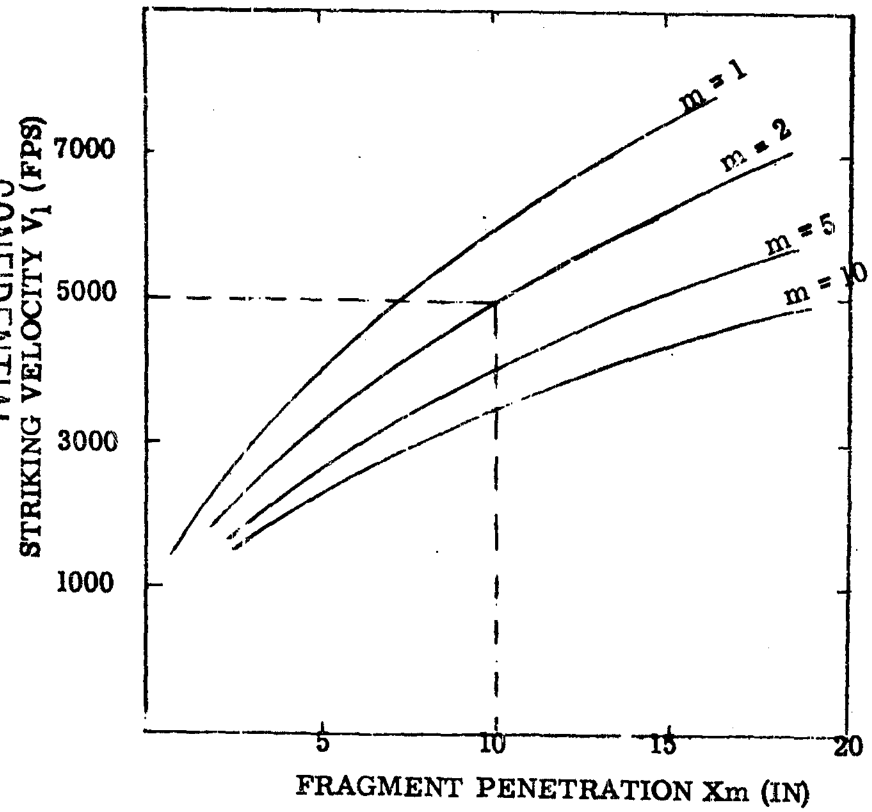
V_2 - RESIDUAL VELOCITY OF PRIMARY FRAGMENTS (FPS)

T - WALL THICKNESS (IN)

Xm - MAXIMUM FRAGMENT PENETRATION (IN)

SLIDE 3

PRIMARY FRAGMENT STRIKING VELOCITY
VS
MAXIMUM PENETRATION

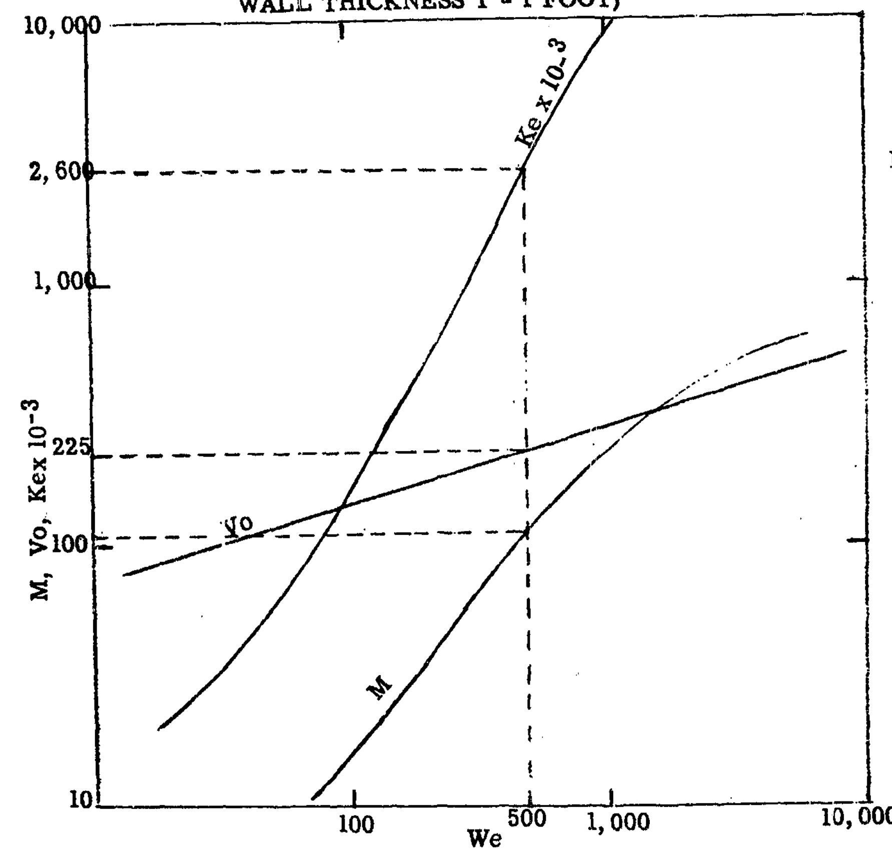


V_1 - STRIKING VELOCITY OF PRIMARY FRAGMENT (FPS)

Xm - MAXIMUM FRAGMENT PENETRATION (IN)

m - FRAGMENT WEIGHT (OZ)

SLIDE 4
CHARGE WEIGHT
VS
MASS, VELOCITY AND KINETIC ENERGY OF
THE PUNCHED OUT FRAGMENT
(REDUCED DISTANCE Z = 0.5
WALL THICKNESS T = 1 FOOT)



We - CHARGE WEIGHT (LBS)

Ke - KINETIC ENERGY OF THE SECONDARY FRAGMENT (FT LBS)

M - MASS OF THE SECONDARY FRAGMENT $\left(\frac{\text{LBS SEC}^2}{\text{FT}}\right)$

Vo - VELOCITY OF THE SECONDARY FRAGMENT (FPS)

velocity of the punched out fragment, and consequently its kinetic energy, will be reduced by a certain amount depending on the amount of energy absorbed as a result of straining the stirrups in the main reinforcement. Without going into details of calculating this reduction, the amount by which the velocity is reduced in our illustrative example amounts to less than 2%. Therefore it is negligible. It is of interest to note that in a similar design situation where the donor charge is smaller and/or further from the wall, the benefit of shear reinforcement is increased appreciably.

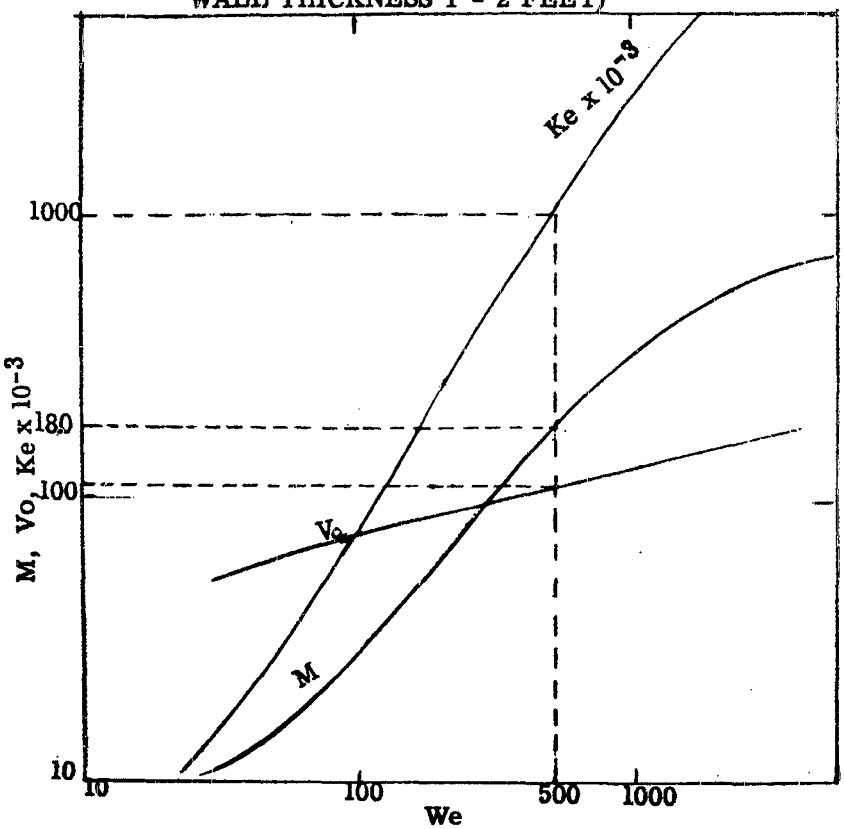
Next, increasing the wall thickness from 1 foot to 2 feet will be investigated. Slide 5 representing the same variables as Slide 4 but for a wall 2 feet thick, shows that the kinetic energy of the punched out piece is equal to 1,000,000 ft.-lbs., which is our assumed maximum allowable value to prevent propagation. Therefore, to bring the design just into the safety zone, a somewhat thicker wall (e.g. 2.5 feet) could be constructed. Protective design could also have been accomplished by erecting a sandwich-type wall with two 1 foot concrete walls with 1 foot thick sand fill between them. The kinetic energy of the punched out piece in this case would be 650,000 ft.-lbs., thereby providing protection against propagation to a much greater extent than the 2 feet concrete wall mentioned before. This method is a very effective means of preventing the propagation of detonation.

The spalling mode of wall failure is now investigated for the 2 feet wall. Slide 6 relating the donor charge weight with the spalled mass and its kinetic energy indicates that for a donor charge of 500 lbs. of TNT and reduced distance of 0.5, the kinetic energy and velocity of the spalls are equal to 46,000 ft.-lbs. and 26 ft/sec. respectively. These indicate that in our illustrative example, spalling is not a controlling factor in the design of a new wall for prevention of propagation, and does not have to be considered any further.

Next in our design, the height of the wall is established to prevent propagation due to blast overpressure (pressure leakage). Slide 7 is the flexural failure chart, which relates donor charge weight, wall height, and wall resistance requirements (in terms of moment capacity) for the condition of incipient wall failure. For any point on the line of constant pressure leakage relating minimum wall height to donor charge weight, the intersection with a constant resistance line indicates the flexural failure threshold for the wall. It indicates the minimum wall height for the 100 psi allowable pressure leakage to be 15 ft. Using this wall height, the previously obtained thickness and a wall resistance less than that corresponding to incipient failure (since wall damage is permitted in this case, as long as propagation does not occur) the required degree of reinforcement is determined. The wall is now completely defined,

SLIDE 5

CHARGE WEIGHT
VS
MASS, VELOCITY AND KINETIC ENERGY OF THE PUNCHED OUT FRAGMENT (REDUCED DISTANCE Z = 0.5 WALL THICKNESS T = 2 FEET)



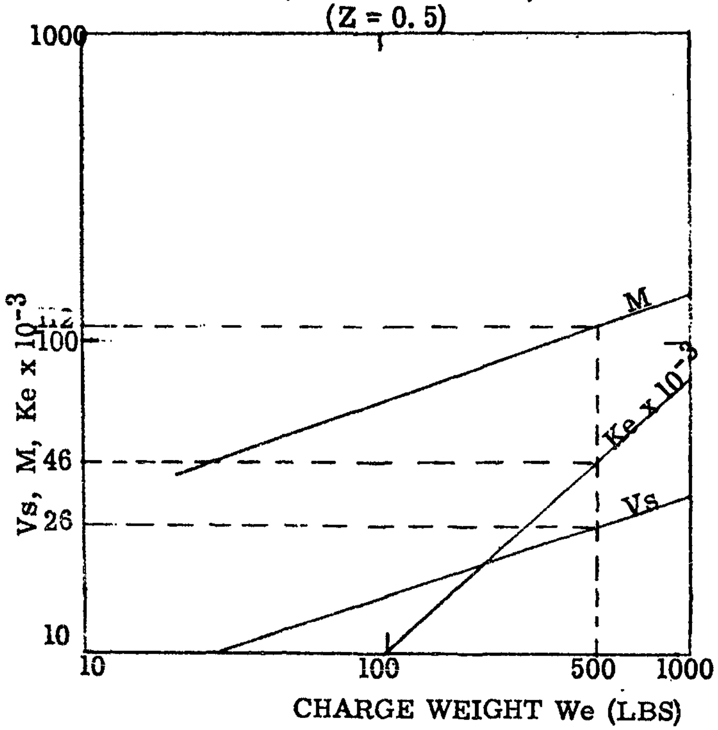
We - CHARGE WEIGHT (LBS)

Ke - KINETIC ENERGY OF THE SECONDARY FRAGMENT (FT LBS)

M - MASS OF THE SECONDARY FRAGMENT $\left(\frac{LBS\ SEC^2}{FT}\right)$

Vo - VELOCITY OF THE SECONDARY FRAGMENT (FPS)

SLIDE 6
CHARGE WEIGHT
VS
VELOCITY, MASS, KINETIC ENERGY
OF THE SPALL
(FOR T = 2 FEET)
(Z = 0.5)



Vs - VELOCITY OF THE SPALL (FT/SEC)

M - MASS OF THE SPALL $\left(\frac{\text{LBS SEC}^2}{\text{FT}}\right)$

Ke - KINETIC ENERGY OF THE SPALL (FT LBS)

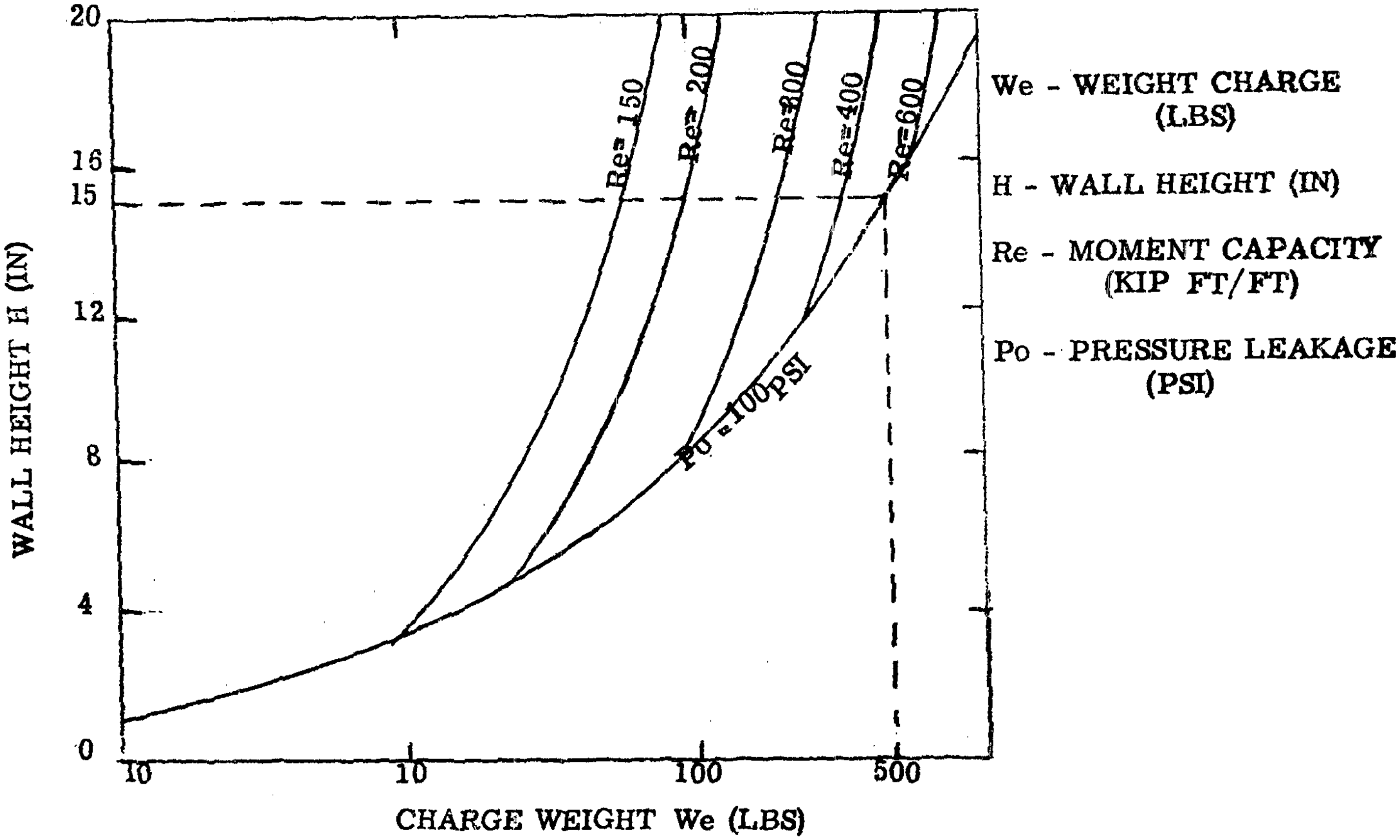
T - THICKNESS OF THE WALL

Z - SCALED DISTANCE

We - CHARGE WEIGHT (LBS)

SLIDE 7

WALL HEIGHT VS CHARGE WEIGHT
(SHOWING VARIOUS REQUIRED MOMENT CAPACITIES AND PRESSURE LEAKAGE LEVEL)
REDUCED DISTANCE Z = 0.5



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ready for checking as to degree of damage (total destruction) relative to acceptor sensitivity.

The final step in our design analysis is to investigate the total destruction mode of failure. Slide 8 is a plot of the maximum kinetic energy which will be produced by failure of a wall due to punching and/or flexural failure vs donor charge weight for various concrete missile masses. This chart may be thought of as being divided into two portions, one, for masses equal to or less than that of the punched out section and the other for masses greater than that of the punched out section. The portion of the chart where the masses are less than the mass of the punched out section will describe the breaking up of this portion of the wall into smaller fragments with higher velocities than that of the punched out piece. The other portion of the chart covers the larger broken section of the wall that have been produced as a result of flexural failure of the wall. If this mode of wall failure indicates no propagation, then the design of the wall is completed. On the other hand, if propagation were indicated by the total destruction mode of failure, the wall thickness as determined by the punching analysis would be increased to the required thickness to prevent propagation. The new thickness would also require a redesign of the reinforcement. The design of the wall would then be completed.

Case 2:

Slide 9 shows the conditions assumed for this example.

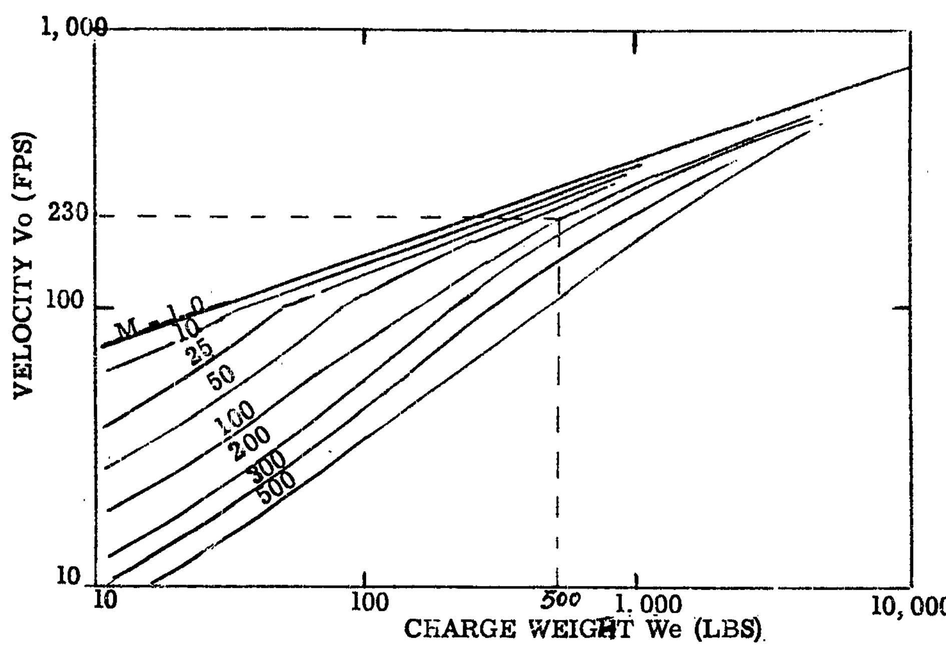
1. Wall thickness = 1 foot
2. Wall height = 15 feet
3. Reinforcement = 1/4%
4. Sensitivity of acceptor to
    a. Pressure leakage = 100 psi
    b. Impact of primary missiles = boundary velocity of 2,000 ft/sec for maximum fragment mass of 2 oz.
    c. Impact of secondary missiles = same as in Case 1.

The variables to be investigated:

1. The allowable donor charge weight
2. Allowable distance between donor charge and wall

SLIDE 8

TOTAL DESTRUCTION CHART
CHARGE WEIGHT
VS
VELOCITY OF SECONDARY FRAGMENTS FOR
VARIOUS FRAGMENT MASSES
(FOR T = 1 FOOT).



We - CHARGE WEIGHT (LBS)

Vo - VELOCITY OF THE SECONDARY FRAGMENTS (FPS)

M - MASS OF THE SECONDARY FRAGMENTS $\left(\frac{\text{LBS SEC}^2}{\text{FT}}\right)$

T - THICKNESS OF THE WALL

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SLIDE 9

INVESTIGATION OF EXISTING WALL TO PREVENT PROPAGATION

GIVEN

1. WALL THICKNESS = 1 FOOT
2. WALL HEIGHT = 15 FEET
3. REINFORCEMENT = 1/4% (ST)
4. SENSITIVITY OF ACCEPTOR TO :
   a. PRESSURE LEAKAGE = 100 psi
   b. IMPACT OF PRIMARY MISSILES = 2, 000 FT/SEC
   c. IMPACT OF SECONDARY MISSILES = SAME AS IN CASE 1

TO BE INVESTIGATED

1. CHARGE WEIGHT
2. DISTANCE (OR REDUCED DISTANCE)
3. STRIKING VELOCITY OF PRIMARY FRAGMENTS
4. SIZE OF PRIMARY MISSILES

3. Striking velocity of primary fragments.

The analysis is again subdivided into two sections: primary fragments and blast overpressure.

The sensitivity of the acceptor to primary missile perforation is first investigated. As in Case 1, perforation of the wall is permitted, and therefore effects of spalling due to primary missile impact need not be considered.

Slide 3 relating the wall striking velocity of the primary missile, V_1, with maximum penetration, Xm, indicates that the maximum allowable penetration (Xm) equals 13.2 in. (for $\frac{T}{Xm} = 0.9$). The maximum allowable striking velocity is, therefore, 6,000 ft/sec. (or given the striking velocity we could compute the maximum allowable fragment mass under the same penetration conditions). Thus, assuming the striking velocity to be essentially equal to initial fragment velocity, the ratio of donor explosive weight to steel casing weight is fixed in accordance with the Gurney equation.

Once primary fragments have been eliminated as a possible source of propagation the allowable values for reduced distance and the charge weight are investigated for punching, spalling, pressure leakage and flexural modes of wall failure due to blast overpressure. First the allowable charge weight is established for punching failure based upon a maximum allowable kinetic energy of 1,000,000 ft.-lbs. at the acceptor - the figure established in our first example. For a 1 foot wall, at a distance of approximately 3 feet from the wall, the charge weight corresponding to this energy is found to be equal to 300 pounds of TNT, on Slide 4.

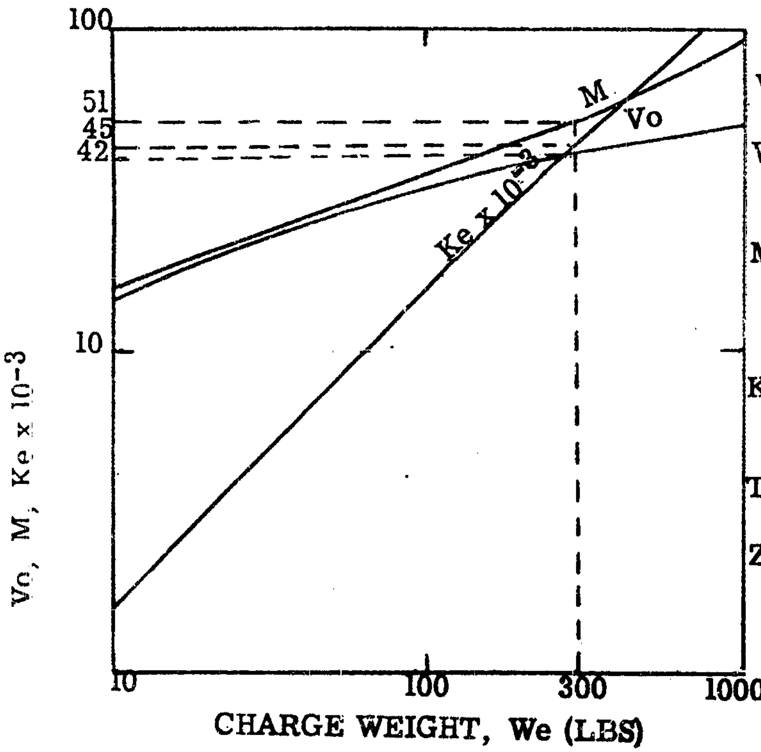
Next the spalling mode of failure is investigated for the 300 pound charge. Slide 6A indicates that for 300 pounds of TNT and reduced distance of 0.5, the total kinetic energy equals 45,000 ft.-lbs. indicating that spalling is not the controlling factor.

Although Slide 7 indicates that for a 15 feet high wall and 100 psi, permissible pressure leakage, a donor charge equivalent to 500 pounds of TNT is permissible, the 300 pounds limit established in the punching analysis is still controlling. It should be noted that since propagation prevention is the objective in this case, wall damage is permissible.

After the charge size has been established for punching, spalling and leakage, it must be investigated to determine whether propagation will occur due to secondary missiles caused by total wall destruction. Using Slide 8 the secondary missile kinetic energies for various mass-velocity combinations corresponding to the 300 pound charge are considered. If this analysis indicates no danger of propagation, then

SLIDE 6A

CHARGE WEIGHT
VS
VELOCITY, MASS AND KINETIC ENERGY OF THE SPALL
(FOR T = 1 FOOT AND Z = 0.5)



We - CHARGE WEIGHT (LBS)

Vo - VELOCITY OF THE SPALL (FT/SEC)

M - MASS OF THE SPALL $\frac{(\text{LBS SEC}^2)}{\text{FT}}$

Ke - KINETIC ENERGY OF THE SPALL (FT LBS)

T - WALL THICKNESS (FT)

Z - REDUCED DISTANCE $\frac{(\text{FT})}{\text{LBS}^{1/3}}$

the design is completed. If, on the other hand, there is an indication that propagation might occur due to secondary missiles caused by total destruction, the allowable donor charge size would have to be adjusted accordingly.

Case 3:

Slide 10 shows the conditions assumed for this example.

1. Distance of donor charge from wall = 7 feet (scaled distance Z = 2.2)

2. Charge weight = 50 pounds

3. Maximum mass of primary fragments = 1 ounce

4. Striking velocity of primary missiles = 5,000 ft/sec.

For the design of a wall which should afford total protection, punching and spalling due to blast must be precluded. Again, the design is divided into two sections, namely primary missiles and blast overpressure.

The thickness of the wall is first obtained to provide complete protection of personnel from primary fragments. In this case, Slide 11, the total protection chart for fragment (no perforation permitted) is used. This slide relating velocity of primary fragment (V_1) with the thickness of the concrete tells us that for a 1 ounce fragment at 5,000 ft/sec. striking velocity the wall thickness required is 8.0 inches.

After the thickness required for fragments is established, the wall thickness required to prevent punching and spalling failure due to blast is studied. Slide 12 relating the charge weight with the scaled distance for various wall thicknesses indicates that in order to eliminate spalling a wall thickness of 2 feet is necessary for the charge and distance in question. Furthermore, our studies have shown that if the wall is designed in such a way that no spalling occurs, then no punching will occur.

The next step in our analysis is to obtain the height and minimum reinforcement for the 2 feet thick wall to prevent pressure leakage and flexural failure. For total protection an enclosed structure must be used. Otherwise the height of the wall for the allowable pressure leakage (of the order of 1 psi) would be prohibitive. In this case, then, the effects of leakage may be neglected. The height of wall as well as reinforcement of the 2 feet thick wall are established from the flexural chart presented on Slide 13. This

SLIDE 10

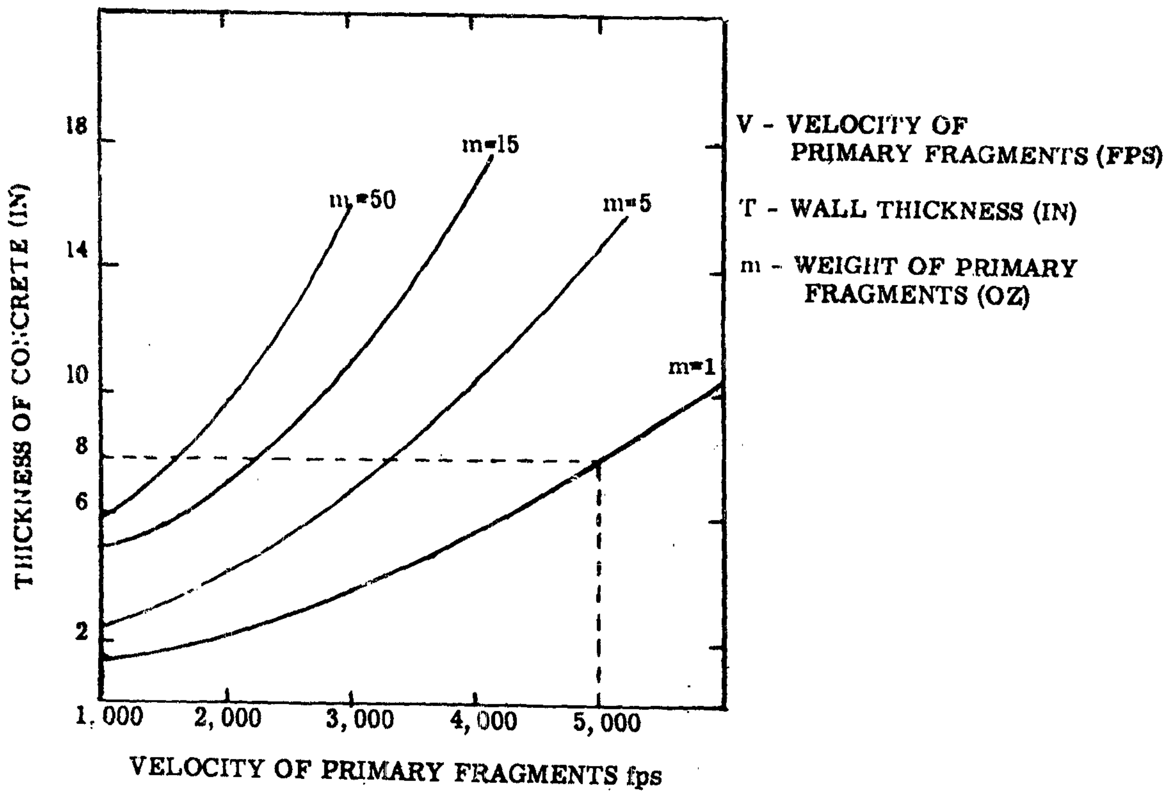
DESIGN OF THE WALL TO PROVIDE TOTAL PROTECTION

GIVEN

CHARGE WEIGHT = 50# OF TNT
DISTANCE FROM THE WALL = 7 FEET (Z - 2. 2)
MASS OF PRIMARY FRAGMENT = 1 OZ
VELOCITY OF PRIMARY FRAGMENT = 5, 000 FT/SEC

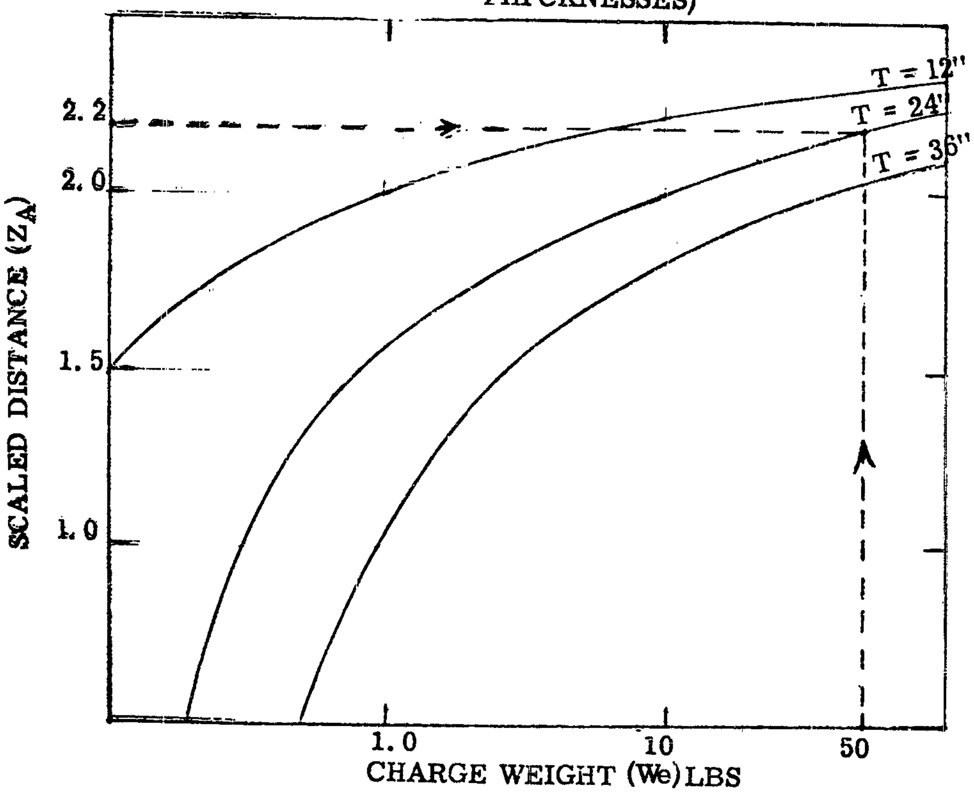
SLIDE 11

**VELOCITY OF PRIMARY FRAGMENTS
VS
THICKNESS OF THE WALL**



SLIDE 12

CHARGE WEIGHT
VS
SCALED DISTANCE (FOR VARIOUS WALL THICKNESSES)

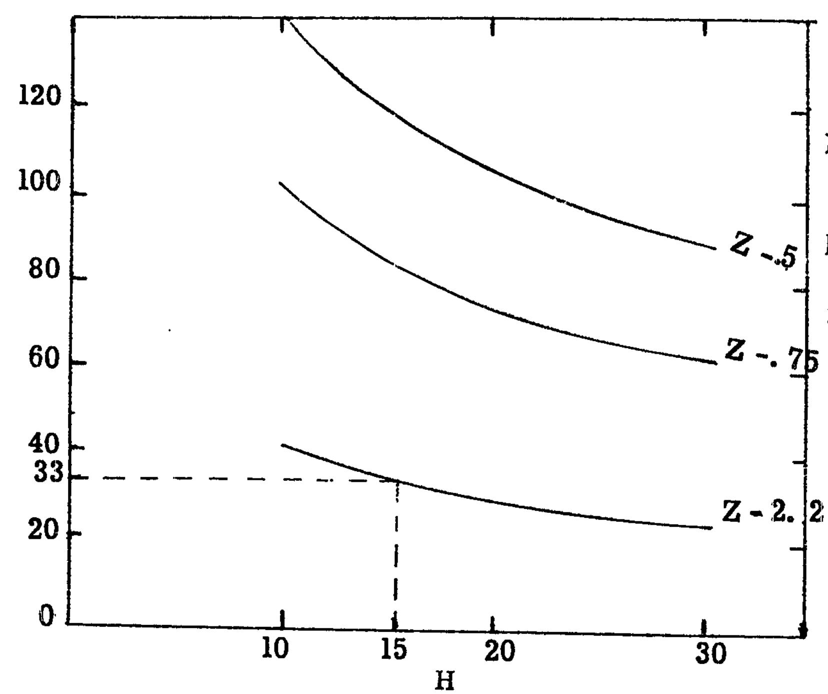


We - CHARGE WEIGHT (LBS)

Z_A - SCALED DISTANCE ($FT/LBS^{1/3}$)

T - WALL THICKNESS (IN)

SLIDE 13
REQUIRED MOMENT CAPACITY
VS
WALL HEIGHT
(FOR 50 LBS EXPLOSIVE CHARGE)



Re - REQUIRED MOMENT CAPACITY (KIP FT/FT)

H - WALL HEIGHT (FT)

Z - REDUCED DISTANCE (FT/LBS$^{1/3}$)

chart relates the charge weight and the wall height for various wall strength requirements expressed in terms of moment capacities, for restrained walls. The degree of reinforcement is calculated so that the capacity required to prevent flexural failure can be obtained using the previously established (from spalling analysis) wall thickness of 2 feet. For reduced distance Z = 2.2 and a 15 feet high wall the moment capacity required equals 33 kip-ft/ft, which for the 2 feet thick wall corresponds to 1/4% reinforcement. The design is now complete.

Case 4

In the investigation of an existing wall for total protection essentially the same approach is taken as in Case 2 except that the wall must be designed to resist all possible modes of wall failure.

As indicated in the examples discussed in this paper, it appears, from our studies to date, that the hazard of secondary missiles resulting from punching and/or total destruction due to blast, rather than the primary missile hazard, should be the major consideration in design of new, and utilization of existing, structures for prevention of propagation. In the design of a wall for personnel protection, the controlling mode of wall failure appears to be spalling due to blast.

In conclusion I would like to point out that we are planning a confirmatory test program to check out results of our studies to date.

Ref. 1. Picatinny Arsenal Technical Report DB-TR: 6-59, R. M. Rindner, "Establishment of Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations Report No. 2 Detonation by Fragment Impact."

Ref. 2. Picatinny Arsenal Technical Report DB-TR: 1-59, R. M. Rindner, "Establishment of Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations Report No. 1 Sympathetic Detonation."

Dr. Ockert: With regard to your initial wall studies, the best I can recall them, you had a 1' wall, a 2' wall and two 1' walls separated by a third foot of sand, is that right?

Mr. Rindner: That's right.

Dr. Ockert: What I'm curious to know is, what if you had taken the 2' wall and taken out the 1' center and filled that with sand. You should have a relative reduction but of course then you do have a 3' wall in the third case. I would be interested to know what

conclusions you draw from the use of sand or air for that matter between those two 1' walls.

Mr. Rindner: But you notice one thing only, that the introduction of 1' fill is using kinetic energy as compared to 2' walls by 50%.

Mr. Saffian: If you recall, the 2' wall gave us a velocity or kinetic energy of one million foot pounds. What we're saying here is that, this is just an example, we kept the total concrete thickness at 2' and so by introducing sand rather than another foot of concrete, we brought the kinetic energy down to, I believe it was 650,000. Had we used 1/2' concrete walls with a foot of sand between them, perhaps we would have gotten the same effect as a 2' wall.

Dr. Ockert: Supposing you didn't put anything between the two walls, you had two 1' walls with a foot of air between them, how much energy do you get there?

Mr. Saffian: We didn't calculate this, however, I would expect that in terms of penetration, you wouldn't get anywhere nearly as much as with sand because of the additional inertial advantages you have with sand. You have to move all that sand before you can punch out a piece from the far wall, the far wall with respect to the donor. The point of sand is that you are introducing a high density frangible mass which is readily available and quite inexpensive.

Dr. Ockert: I'm a great believer in sand, don't misunderstand me, I just wanted to know the reference number.

Mr. Saffian: We clarified that point.

Dr. Noonan: I think we ought to get together on our pressure business. I'm pretty sure we have enough information on not only Comp. B but some 41 different propellants and about 12 other explosives as to the minimum pressure required to initiate them. This ought to work just as well for your fragments as for any other kind. The thing is, it seems to me that mainly the velocity is the critical factor here, not the kinetic energy or the mass or the fragment. The mass will affect it inasmuch as the hold-up time of the pressure is much longer, in our case it only amounts to 2 to 5 milliseconds but the thing that's doing the initiating is the heating of the propellant from the shock. This depends primarily on the pressure rather than on the time because of the much higher temperature for a very short time does a lot more kinetically than a low pressure for a long time.

Mr. Rindner: We agree with you 100%, the kinetic energy should not be by itself the criterion for establishing how much is necessary to detonate this explosive charge but if you correlate always the kinetic

energy and the net velocity range under investigation, we found that the very high velocities like 7 or 8,000 ft. per sec., all that is necessary in terms of kinetic energy is a few thousand foot pounds. On the other hand if you go into velocities of 100 or 200 ft. per sec., the kinetic energy necessary to propagate the acceptor charge might be in terms of millions of foot pounds, so this is because we are dealing with secondary missiles which are characterized by low velocity and high mass. This is the reason why we assumed such a high number.

Mr. Saffian: One other point, Dr. Noonan, we selected kinetic energy as a rough first approximation, we don't feel certain at all that it is a straight kinetic energy function. It is, I feel, a mass-velocity product of some sort, maybe a mass times velocity to some exponent other than 2. In terms of calculating the velocity of the concrete fragments and in terms of the punched out piece, in going through the calculation procedure you almost have to have a mass in order to calculate the velocity because certainly in terms of the impulse loading on the wall, the momentum, let's say the conservation of momentum considerations on a portion of the wall, in the calculation you come up with momentum. Well, you have to be able to determine the mass in order to get a velocity in any case.

Dr. Noonan: Oh sure, I agree with that.

Mr. Saffian: It may very well be that kinetic energy by itself - in fact we feel certain it's not the only criteria in any case.

Dr. Noonan: Theoretically, at least, the pressure should be proportional to the velocity of the thing hitting the thing struck and the mass doing the hitting doesn't do anything about the pressure, just the way that a depth bomb doesn't have to withstand the whole tonnage of water behind it, just the pressure to the water depth.

Mr. Saffian: One other thing we're concerned about which will depend on the mass of the fragment is in any particular case, I think it was pointed out earlier that, in some cases in any real situation the acceptor will move to the extent that it moves, it is in effect, reducing the energy available to it, for detonation. We have a large chunk of concrete weighing several hundred pounds moving this thing, then something less than all the velocity of that fragment is available to the acceptor charge.

Dr. Noonan: I don't think it will move anywhere in the time it takes to detonate. Another thing I wanted to ask you about was your wall height business and this pressure leakage. If I read you right you were arbitrarily saying although you have an air blast pressure of 100 psi, this is the maximum we can tolerate, is this right?

Mr. Saffian: Yes, that's right. It's an arbitrary figure of 100 psi. We didn't go into the details of some of the earlier work. Let me tell you how we got to that 100 psi. We realized, I think your point is that the value should actually be much higher, is that true?

Dr. Noonan: Yes.

Mr. Saffian: This is a very conservative figure and it's based only on an empirical correlation of data that we combed from various accidental explosions, and test explosions where we were able to establish a boundary corresponding to 100 psi above which propagation did not occur. That's all that 100 psi is and undoubtedly depending on the sensitivity of the explosive, for one thing, by the way I might point out that the explosives included in this data, in establishing the boundary line, included such things as nitroglycerin containing materials such as dynamite, etc. And it's just a very gross figure, let's put it that way, covering the entire area of explosives.

Dr. Noonan: It makes quite a difference in the expense of your walls though because it has to be quite a bit higher. So I think we ought to take a much higher figure than that, this is only a 6 bar pressure whereas we find it takes about 10,000 bars to initiate something like pentolite. Of course, this is for a short duration now. That's another thing we're considering, longer duration of the air blast. But it seems to me it's a very low figure, you could go much higher and build a much lower wall.

Mr. Saffian: That's right.

Dr. Noonan: Incidentally, I think we have compiled all the material from the Polaris program sponsored by Comdr. McCarthy and its NOL TR 61-4. I think this is all of our card gap data on all the explosives and all the propellants we have available. If you want it and don't have it, it has been distributed, write to our Publications Dept. and ask for this giving your contract number. It's Confidential only insofar as the propellant material formulations go.

Col. Hamilton: Thank you very much Mr. Saffian and Mr. Rindner. Our next speaker is Mr. J. E. Settles, Hercules Powder Co., who will discuss 'Design of Protective Structures in the Manufacture of High Energy Solid Propellants.' Mr. Settles.

Mr. Settles: Designing protective structures that will meet functional safety requirements for the manufacture of high energy solid propellants involves three major problems:

1. Protecting explosives from initiation
2. Maintaining the integrity of structures
3. Protecting people

The larger part of this discussion will consider the problem of providing adequate protection for operating personnel who engage in the manufacture of high energy solid propellants. There are some puzzling aspects to this problem. There are appreciable areas of uncertainty. The following are the major ramifications of the problem:

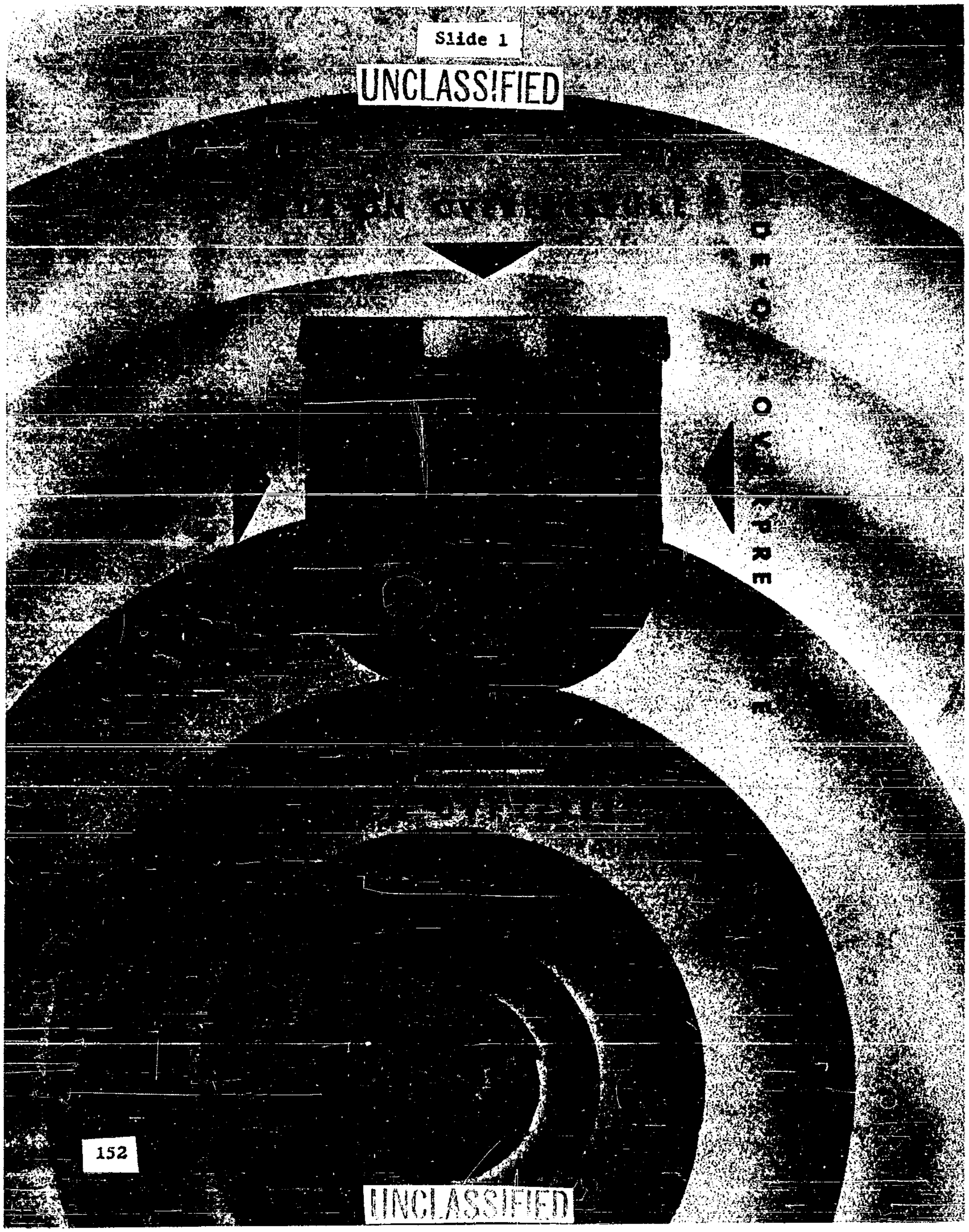
The protective barricade or earth cover which surrounds a building that is adjacent to the site of an explosion (the target barricade and building) is subjected to two levels of pressure greater than atmospheric. This pressure is generally termed "overpressure."

There is a "face-on" overpressure which is applied to that portion of a barricade or building which directly faces the explosion. There is a "side-on" overpressure which is applied to all other exposed portions of the barricade or building. The "face-on" overpressure is approximately double the "side-on" overpressure. For those who may be a little confused about the terminology, Slide 1 will help to clarify the references. A point requiring emphasis is illustrated by Slide 2.

Some of you may not have realized that a side-on magnitude of overpressure exists on the side of a barricade that is farthest away from an explosion - the "lee" side of the barricade. If operating personnel are located at such a point they will be subjected to a side-on magnitude of overpressure. High speed photography has recorded the fact that when a shock wave approaches a barricade it flows up, across and down the lee side, much like flowing water.

An additional and very interesting aspect of the pressure conditions that result from a blast has been reported by the Atomic Energy Commission in a classified document titled, "Nuclear Weapons Blast Phenomenon." The reference, if applied to our problem of personnel protection, can be summarized as follows:

If the intervening mass of material between the operating personnel and the explosion site is in the form of a bombproof shelter, and if the entrance door of the bombproof is made of a frangible material, even though this door is located on the lee side of the bombproof, overpressures will be developed inside of the bombproof that will be almost equal in magnitude to the side-on overpressures that occur outside the bombproof. It is reported that some data developed in studies by the Rand Corporation support this concept.


Slide 1
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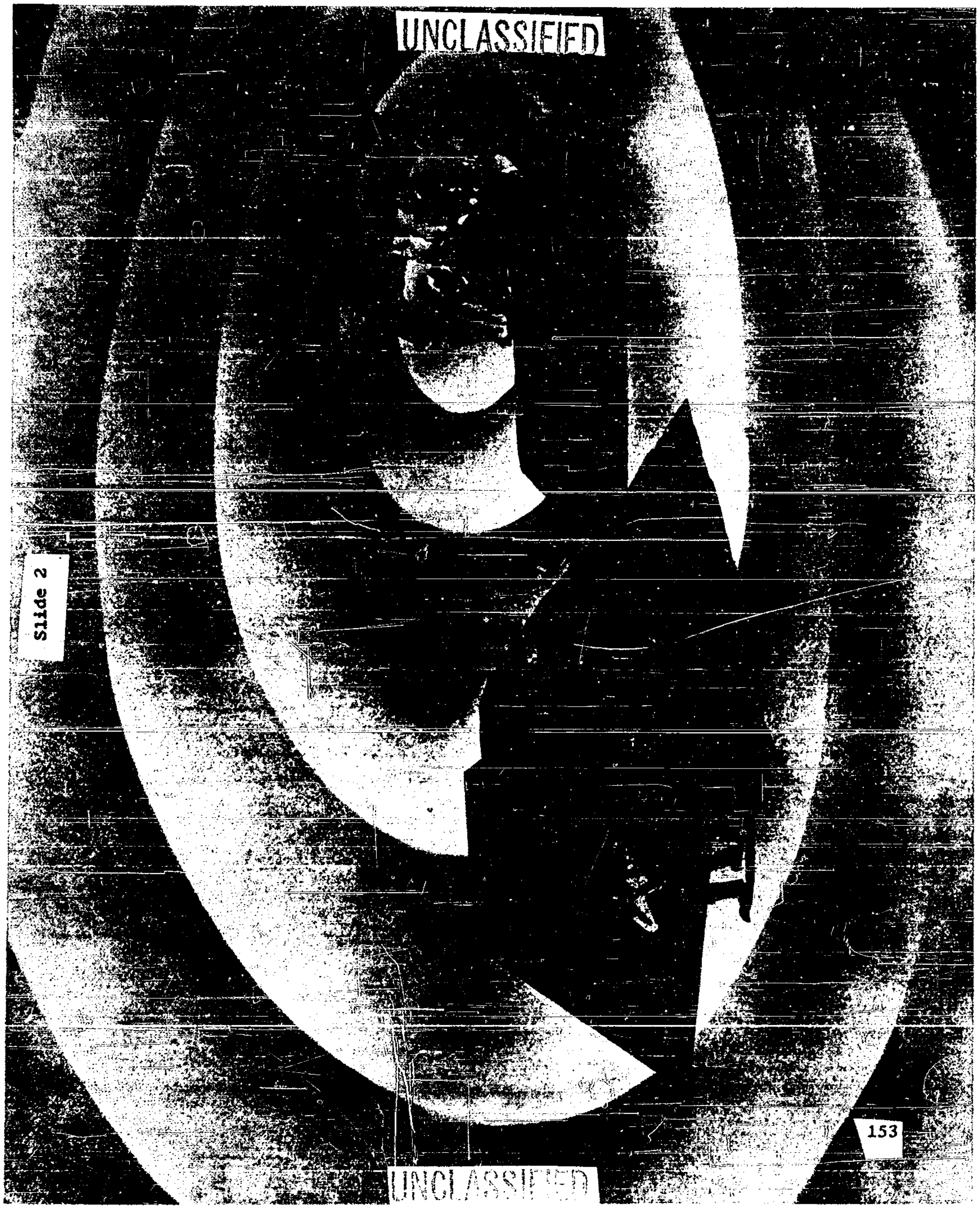
UNCLASSIFIED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Slide 2
153
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The implications of these statements are very disturbing. The following slide (Slide 3) will help to clarify the point of greatest concern. Note the mass of material that surrounds the operator; reinforced concrete and an earth cover. The weakest point in his protection is the frangible door. This might be an ordinary wood door that is intended to do no more than keep out undesirable weather conditions, or it might be a conventional safety door. However, if the precaution has been taken to locate this door on the side of the bombproof that is farthest away from the explosion site most of us would feel the safety of the workers is measurably improved. The AEC data says, in effect, the frangible door makes the bombproof superfluous, so far as pressure conditions are concerned. A simple vertical barricade would give as much protection. If the door collapses under the side-on overpressures generated by the blast, practically the same magnitude of overpressure will exist inside of the bombproof as is applied on the exterior lee side of the structure. It should be re-emphasized that all references here consider the pressure problem only. Missiles are another consideration.

According to the published report it is possible to make the bombproof a very effective structure against pressure by an expedient which is illustrated by Slide 4.

With the egress portale to the bombproof covered by a door that has sufficient mass to withstand all values of overpressure that will occur, the personnel inside will be adequately protected.

It would seem the problem could be solved quite readily then by the simple expedient of covering the egress port from each bombproof with a door of sufficient rigidity that it will withstand all potential overpressures. However, from the viewpoint of safety men there is another probability that must be considered. Successful operation of a plant will not permit blowing up an operation on frequent intervals. In fact, it can be expected other safety precautions will assure the explosion for which the protection is being provided will occur only once every 3, 5, or 10 years. During this 3, 5, or 10-year period of uneventful operation, laxity is certain to creep in. So it is a very good probability, and it must be expected, that at the very instant the explosion occurs someone has left the bombproof door open.

An additional aspect of the problem is revealed by data on the magnitude of overpressure that will result from initiating various quantities of explosives at various distances from the site of an explosion. The following set of curves were developed by the Armed Services Explosives Safety Board. They represent a summarization of available data on overpressure (Slide 5).

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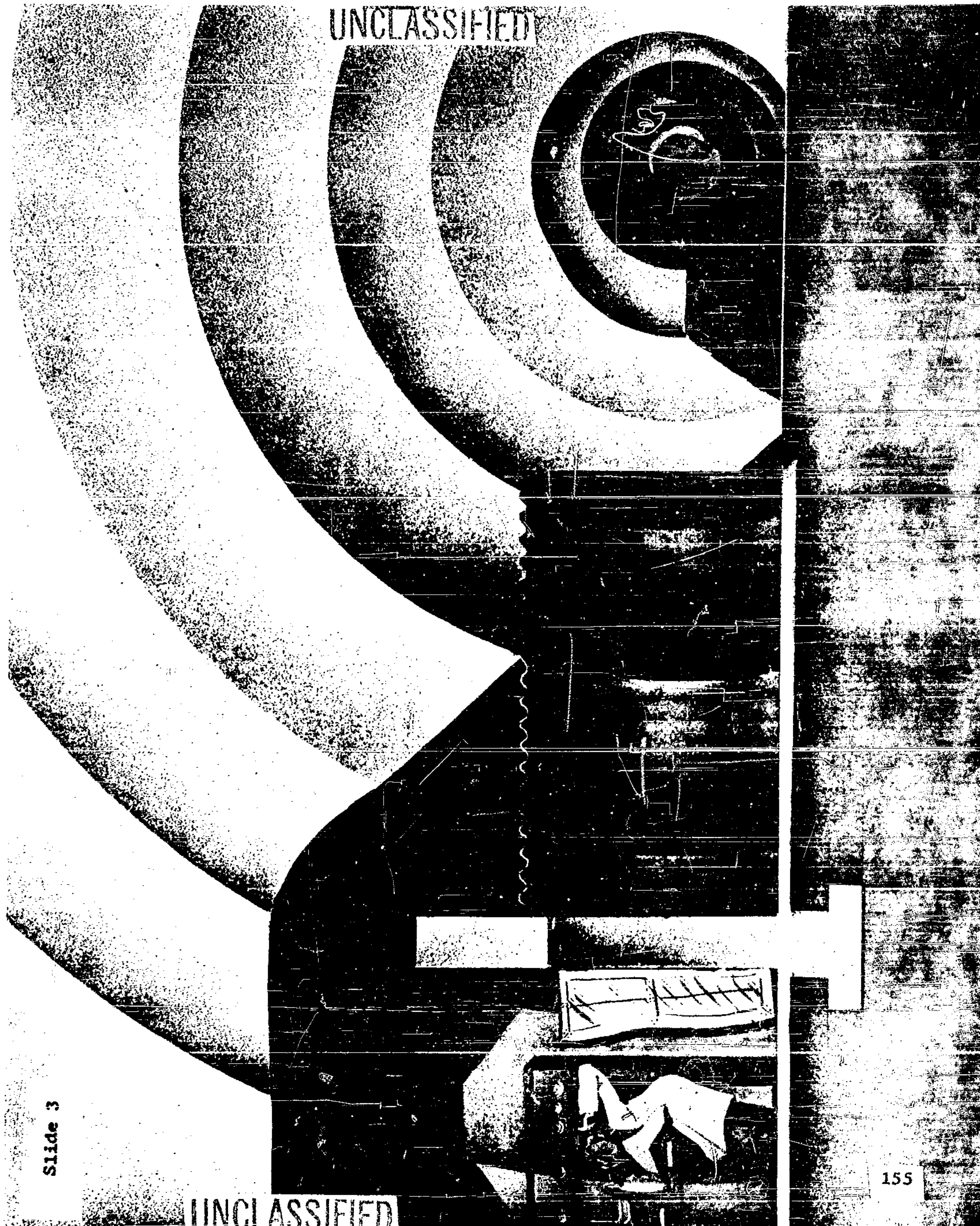

Slide 3

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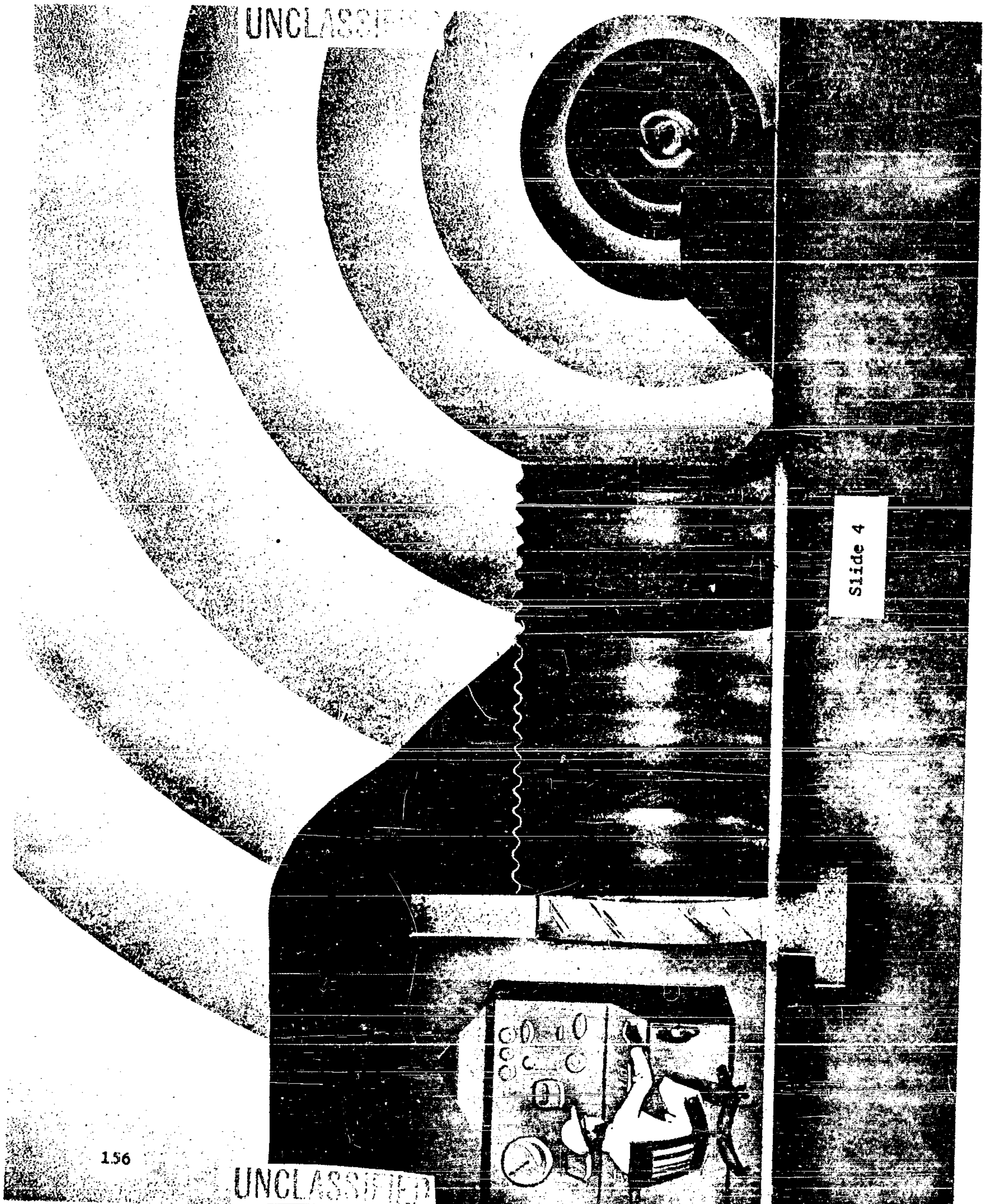

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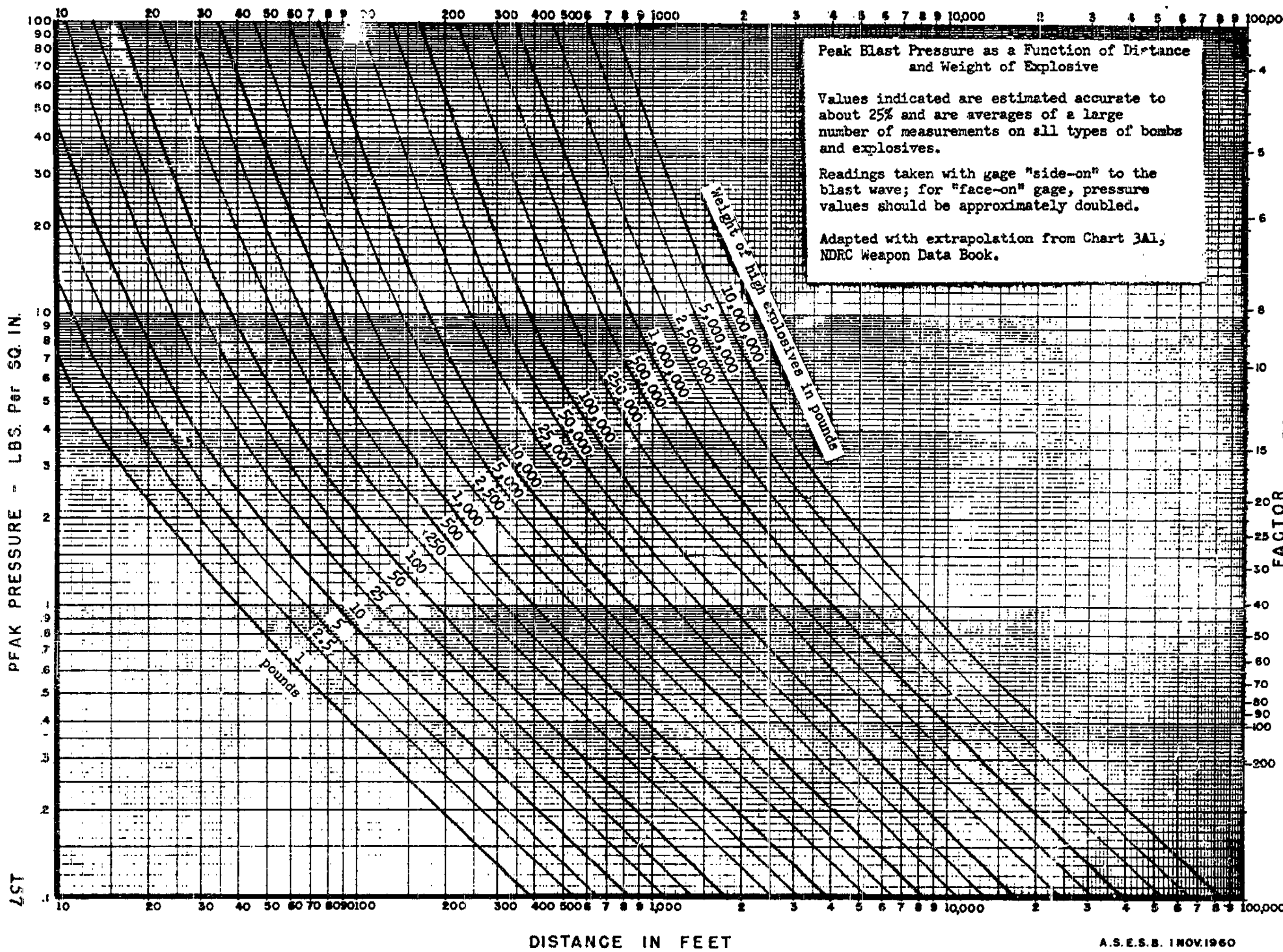
Slide 5



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Each curve on the scale represents a stated poundage of explosives. Pressure in pound per square inch is indicated along the left side of the slide. Distance in feet can be read along the top and bottom of the slide. These data represent side-on overpressure only. Face-on overpressures will be approximately double the indicated figures. By following the 500 pound curve, it is developed that an overpressure of approximately 4.8 pounds per square inch will be experienced at a distance of 100 feet. The curve for 5,000 pounds shows an overpressure of approximately 25 psi at a distance of 100 feet. The curve for 25,000 pounds indicates an overpressure of approximately 100 psi at a distance of approximately 100 feet.

It should be emphasized the data is not represented to be accurate to a value closer than 25% of the indicated pressures and distances. This is as accurate as present information will permit and it is a very commendable effort considering that the magnitude of any overpressure is a function of many variables, the three most important of which are: (a) The formula of the reacting material, (b) The quantity of the reacting material and (c) The distance from the blast at which measurements are taken.

It is the capability of this overpressure to cause injury to people that is of primary concern at this time. Consider the following facts which are pertinent to this part of the problem:

Air Force representatives in recent correspondence summarized data which is available to them with the statement that maximum overpressure humans can withstand is approximately 35 pounds per square inch. It was indicated pressures only a little above this level will result fatally. This same correspondence indicated an overpressure of approximately 29 psi would result in ruptured eardrums.

A classified report titled, "Fundamentals of Protective Design" published by the Corps of Engineers in 1946 contains the following statement: "The effects of blast on the human body have been greatly overestimated in the past. It has been shown that brief peak pressures of 50 pounds per square inch can be tolerated."

Recent discussions with Navy personnel developed the information that an opinion was recently given by the Navy Bureau of Medicine which indicated overpressures of as low as 5 psi can result in ruptured eardrums and overpressures of as low as 15 psi can result fatally.

It must be recognized the amount of injury which will result to an individual from overpressures will depend to a considerable extent on the physical conditions of the individual. This can be quite a variable and probably accounts in part for the variability in opinions and data.

In passing it might be observed that if a worker inadvertently has his mouth open and is drawing a breath at the exact instant the overpressure occurs, permitting application of the overpressure directly on internal lung areas, he would seem to be in the most vulnerable possible condition.

The scope of the problem being discussed will be clarified by quickly reviewing the three sets of pertinent considerations that have been presented up to this point:

First, there are data on record that have been developed by sources of considerable eminence which indicate that unless personnel are surrounded one hundred per cent by structurally sound bombproof protection they will be subjected to side-on magnitudes of overpressure at a given distance from the site of an explosion.

Second, values of peak blast pressure under side-on conditions, that may be expected at stated distances from the center of an explosion have been reviewed.

Third, there are data, or at least opinions, which indicate overpressures may be fatal in a range anywhere from 15 psi to 50 psi.

In a moment three case histories will be reviewed, and there are more, which do one of two things. These case histories indicate either: No. 1 - one or all of the three sets of considerations which we have reviewed are in error; or No. 2 - There is a factor other than pressure magnitude and structural mass which must be taken into consideration.

In fact, there is another factor and its more important aspects should be discussed. This additional factor is the time interval through which a peak blast pressure, or overpressure, exists. It is the impulse factor. It is a measure of one aspect of a dynamic condition.

Data from the Arco, Idaho tests conducted by the Army-Navy Explosives Safety Board (now the ASESB) in 1945 and 1946 indicate an overpressure from a blast may exist for a period of time as short as 37 milliseconds or as long as 100 milliseconds or more. The duration depends to a large extent upon distance from the blast.

The question that is now presented is "Does an overpressure of 40 psi that exists for 1/30 of a second have the same lethal characteristics as an overpressure of 40 psi that exists for one second or two seconds?" What is the inertia of human tissue? How long does it take flesh and bone to respond to conditions of overpressure?

It probably would be inadvisable to argue with the medical folks on any value they quote for lethal overpressure. The folks from the Armed Services Explosives Safety Board have presented the best data available on values for side-on overpressures at given distances from a blast center. It should be expected the AEC has defendable data on the mass of material required to protect people. However, if these folks are all correct, it is strongly indicated the duration of the overpressure is a factor which must be accurately evaluated.

The following are some of the facts from actual case histories which emphasize the need for a thorough study of the problem. These facts will cite instances in which operating personnel have been exposed to overpressure conditions that should have resulted fatally but did not.

The first instance occurred at Allegany Ballistics Laboratory on May 22 of this year. Later in this meeting Dr. A. M. Ball will present a comprehensive review of this particular accident. At this time, your attention is directed to just one result of the explosion. Slide 6 will present the locale before the explosion. This is a view of the building at Allegany Ballistics Laboratory which was completely destroyed in the explosion. An operating supervisor and a helper in a pickup truck arrived at a point almost directly under the telefer system at the exact instant the explosion occurred. The supervisor stated he has opened the truck door. The location of the truck with its two human occupants at the time of the explosion was within from 30-100 feet of the exact center of the explosion depending upon where it is determined the center of the explosion was. A total of 8,000 pounds of material reacted during the incident. Some of this material was as much as 100 feet from the truck location and some of it was as close as 30 feet.

Slide 7 presents an interesting view of the same scene. This is a view of the truck after the explosion occurred. The force of the explosion drove the truck backward for a distance of some 50 feet. The supervisor and his helper were inside of the cab which you see crushed by the debris. The supervisor was practically uninjured. The helper was injured by the debris crushing in the roof of the cab. However, the injuries were not fatal. The overpressures to which these men were subjected, according to the table which was previously presented, could have been anywhere between 30 and 100 psi.

Slide 8 is a distance view of the same scene from the opposite side of the truck.


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Slide 3

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The second incident occurred at the Kenvil Works of Hercules Powder Company in October 1959. Two propellant mixers, each containing 500 pounds of high energy material, were initiated and detonations resulted.

Whether the two mixers reacted sufficiently near the same time to give an explosive force equivalent to 1,000 pounds of material could not be positively determined. However, two operating personnel and one quality control technician were on the lee side of a 20 foot high barricade within 30 feet of the site of the nearest mixer. The quality control technician survived with no injuries more severe than scratches. He was housed in a wood frame structure that had no resemblence to a bombproof shelter. According to our overpressure table this man was subjected to overpressures of greater than 80 pounds per square inch.

In addition to these two incidents, some very pertinent aspects of the problem can be obtained from an accident that occurred at Aerojet General's Sacramento Plant in 1957. The reason for mentioning this incident is that the folks at the ASESB have indicated they have reviewed, and were impressed by, the fact that operating personnel survived the apparent overpressures of this particular incident.

According to published details of the occurrence two workmen were in a barricaded control shelter within 30 feet of a mixer containing 500 pounds of high impulse material which reacted high order. The control shelter was not a bombproof. According to the peak blast pressure data reviewed a few minutes ago the two workmen survived overpressures in excess of 80 psi with only minor injuries.

In order to clarify the position of most of us in this meeting it probably would be well at this time to review briefly the existing safety regulations concerning location of personnel protection shelters for operations which are remotely controlled.

Ordnance Safety Manual ORDM 7-224 makes personnel protection an advisory requirement with a statement which is contained in paragraph 2622: "When personnel protection is required for operations involving quantities of explosives in excess of 70 pounds, providing a suitable protective shield often becomes impractical. In such cases the operator should perform the work by remote control from a barricaded positio not closer than the appropriate barricaded intraline distance." ORDM 7-230 leaves no latitude for discretion. It says in Section 10, paragraph A, "Provisions of paragraph 2622 in ORDM 7-224 are mandatory where an explosion hazard exists."

The Navy Safety Manual, OP 5, Volume I, Revision 2 says: "Guard shelters, surveillance buildings, pump houses, heating buildings,

bombproofs or other personnel shelters and auxiliary buildings in the magazine area and operating lines are not considered as inhabited buildings. Such buildings or shelters shall be located as far as practicable from magazines and main operating buildings containing explosives and ammunition and preferably not less than the appropriate magazine distance or intraplant distance prescribed for the quantity and kind of ammunition or explosives involved."

The side-on overpressures that will occur at intraline distances from the site of an explosion fall approximately in the 8 to 9 psi range. The many difficulties and unusual problems that seem to confront any attempt to design adequate protective structures for the regions of higher pressures probably lead some of you to ask, "Why do you bother? Why not retreat to intraline distances and quit worrying about the problems?"

It should be pointed out that many existing facilities were designed for manual operations. As more energetic and more sensitive ingredients are put into our propellant formulas it becomes very desirable and in some cases mandatory that the operations be controlled remotely. In many existing plants there isn't sufficient space to permit locating control shelters at intraline distances.

An additional factor is that some new operations require repetitive inspection of the product or adjustment of remotely controlled equipment. This becomes most uneconomical from shelters that are located at intraline distances. For example, if a machining operation is involved in which several different cuts must be made on a 5000 pound rocket charge, a remote control shelter located at intraline distance would be 150 feet away. Each adjustment of the machine would require operating personnel to walk to and from the operating building, or a distance of 300 feet - 100 yards - the length of a football field. According to the peak pressure chart we examined a few minutes ago, the overpressure at 150 feet for 5,000 pounds of propellant would be 9 psi.

However, according to the three incidents just cited, personnel have survived, with only minor injuries from other sources, in regions where overpressures should have been in excess of 80 psi. If a remote control shelter for a 5,000 pound hazard were located in the 80 psi region it would be approximately 62 feet from the operating building, instead of 150 feet.

In Hercules efforts to date, bombproofs for personnel have been located in the 30 psi pressure region. Frankly, it would be desirable to move in as close as the 80 to 100 psi region, if it can be established that it is safe.

There are two related problems that should be mentioned. The effects of overpressure on structures is a major consideration. If the time interval of the overpressure is an appreciable factor in any resulting damage to the human body it must also be an appreciable factor in the magnitude of damage that will result to a building and the structural members of a building. The inertia of a structural mass is certainly greater than that of a human body, even though human tissue has superior elasticity.

The Corps of Engineers Manual covering the "Fundamentals of Protective Design" makes the following positive statements about the problem: "The absolute duration of the load (blast pressure) is not as significant in an analysis of the behavior of the structure subjected to it as is the ratio of the duration of the load to some characteristic period associated with the structure ..... The factors involved are the magnitude of the impulsive load, duration of the load, the period of the structure subjected to the load, the dynamic load factor and the equivalent static load."

Some half dozen pages immediately following these statements in the manual are devoted to a detailed treatment of the mathematical support for the statements. Hercules structural engineers are in the process of interpreting the equations into terms of concrete and steel. No definitive statements have been issued to date.

There is another precaution which must be taken as personnel shelters are moved closer to sites of potential explosions. Contamination of the atmosphere inside of bombproof by combustion products which result from an explosion can result in an appreciable hazard to personnel.

Passage of a pressure wave over spaces that are largely confined, such as a bombproof, will change the composition of the atmosphere inside the bombproof by dilution with the products of combustion. This contamination should be in approximately the same ratio as the magnitude of the pressure wave to normal atmospheric pressure. The contaminated atmosphere within the enclosure will persist because diffusion and convection are greatly retarded by the surrounding walls. When we evaluate the known human requirement for oxygen and the human tolerance for carbon monoxide and other products of combustion it is strongly indicated that enclosures, such as bombproofs, which are located in the pressure wave region should be supplied with supplementary oxygen sources, or means of excluding the CO, such as gas masks.

The problem of the physical location and structural adequacy of protective shelters for personnel has become a major concern for Hercules design and safety engineers during the last several

months. Details of the problem have been presented here with the thought others of you may be struggling with similar perplexities.

It may be that answers already exist for some of the questions that have been presented. If so, citing of references will be appreciated. If answers do not exist, it seems obvious the magnitude of time and money that will be required to develop reliable and comprehensive data will be an appreciable problem. Perhaps we can all share in the development of the data and also share the advancement in the state-of-the-art which the data brings about.

Col. Hamilton: Does anyone have any questions?

Mr. Ullian: I'd like to refer to you and anyone else that is interested to the work that has been done by Dr. Clayton White. They have samples on dogs, guinea pigs and everything but human beings, I imagine over a thousand samples from all the AEC tests. And I think probably this is where the Navy got the 5 psi incident overpressure for eardrum damage, 15 psi overpressure for lung damage and about 25 psi for fatalities. One of the things that Dr. White points out and also other people with a little more foundation who have done extensive work with the AEC in this area is that they use what they call an average man and they admit that various individuals may withstand greater or lesser amounts of overpressure. The other point that I think is worth mentioning is that Dr. White mentioned above over 25 psi and the reason we were interested in this was our blockhouse at the Cape. Unless you have an airtight structure, I think as you pointed out in your last point, the rarefied gases and the overpressure wave creates a temperature problem that in many cases, in the AEC tests with dogs, killed the dogs from temperature exposure, not overpressure. In other words, if there were any leaks or any way that the heated air could get into the structure, through vent ducts, or by poorly sealed doors at pressures above 25 pounds overpressure, they got nearly 100% fatalities among their guinea pigs just from the temperature rise. Another point I would like to bring out and ask the question, you mentioned three incidents. I wonder how many other incidents there have been and I personally know of quite a few where people have been killed with overpressures of as low as 25 psi and if you're interested to substantiate these with various documents from 50 to 100 cases.

Mr. Settles: Mr. Ullian, I know that you folks at Cape Canaveral are as close to this problem as probably anyone else in the industry because you have to live with it day by day. Now, I would appreciate getting that reference from you and the point I think we want to make by this presentation here is not to establish necessarily exactly where these lethal levels of overpressure are but rather why do we have the variability, what is the condition, what is the effect of this time interval. Is it an appreciable factor or is it something that we are just asking questions about and it has no consideration. Another thing I am wondering, is do guinea pigs and other animals react the same way as humans do?

Mr. Ullian: As I said, I'm certainly not an expert in the medical areas of this at all. We did spend some week and a half just the last month talking to Dr. Clayton White who is recognized in medical circles as probably one of the best experts or nationally recognized experts in the country. First of all I would recommend that you all contact Dr. White. He has a library nearly half the size of this room just on this problem. I think probably he would be the man to answer your question. I agree with you, we have again found out in a study we just finished, there is much unknown and little known

all that anyone can give you including Dr. White are generalized statements because as you pointed out, they can only assume that guinea pigs, dogs, rabbits, etc. will act similarly to human beings in many of these cases. I'm with you, I'm not against you.

Lt. Kaplan, AFBMD: There is a great deal of information on this protective design that has been done by Dr. Nunmark of the University of Illinois and this covers this period of the structure and the duration, etc. and I don't see why you wouldn't be able to get this.

Mr. Settles: Lt. there is such a tremendous mass of data that is available, as I tried to dig through it, I found to my chagrin that most of it is not applicable to the particular problem we have at hand. Nevertheless in some of this data, there may be very pertinent facts that we should know and I should have dug out before I presented this paper, but I didn't have time.

Lt. Kaplan: I think you would get some valuable information out of these papers. One other comment I had was, this Corps of Engineers Protective Construction Manual has a TNT chart in there. This thing is valid only from 5 to 30 psi and there has been a lower chart made up, I think the one you have is actually the lower one, which covers the whole range much more accurately and I think we should be careful not to use the Corps of Engineers chart out of these limits.

Mr. Gus Economy, DIG/S, Norton AFB: I have a question here, perhaps you could answer for me or perhaps a member from the ASESB can. Investigation of recent accidents involving missiles indicated that we have a serious hazard due to secondary missiles. The number of missiles and the weight of these missiles have gone out beyond our present siting criteria which was based on peak overpressures. What information do we have for the probability of risks, due to missiles?

Mr. Settles: This missile problem and I would emphasize this strongly, is another problem of as serious if not more serious magnitude than the overpressure problem. I can't delineate upon it right now. But you are right, there is a tremendous problem here and you folks who are designing protective structures should be very careful to consider this part of the problem.

Mr. Economy: Perhaps a member from the ASESB could answer me, what risk or probability are we willing to assume due to missiles?

Mr. Settles: They'd say none I expect.

Col. Hamilton: Mr. Perkins, would you care to comment on this?

Mr. Perkins: There has never been a time in my recollection that we haven't called to the attention of everybody who asked the question that they would not be with incidents of this type, a hazard from debris beyond the high explosive blast hazard distance that might be expected from those things which as in the instance Mr. Economy mentioned produce missiles as a primary hazard rather than blast. The question of how much hazard you were going to accept, what the degree of hazard which you can accept from these incidents is one which you must decide upon. We will tell you that at certain distances you will have a hazard and in the case mentioned, this was such that there was a severe hazard within a reasonable radius which we have used for years as a protective distance around missile or fragment producing sites. If you decide that you wish to protect from missiles that are thrown further, we have to set up some standard as to how many of these missiles in any given acre or 10,000 square feet you can accept. We do not have agreement on information standards of this type yet. There are people who would like to limit the hazard to say, one hazardous missile for every 10,000 square feet. Others would like to use a lesser figure, but we have no way to determine exactly what risk you may take. You have to decide this yourselves on the basis of the operational necessity for placing something at a certain site when you know it has a potential of throwing fragments several hundred feet further than the normal safety zones provided. I don't think I should speak at further length on this subject.

Mr. Settles: Mr. Economy, could I add this thought. As we go to bombproofs, our intention is to completely protect at least the operating personnel from missiles. I grant you there are other folks working in the plant who are subjected to missiles from some of these major accidents. So that is a problem and how you protect them from it or can you. It may be an inevitable risk that we have to take.

Mr. Jezek: With regard to this business of missiles and blast, to give you an example of how unpredictible things could be, recently we had an incident where a man was standing within 20 ft. of a 500 pound bomb covered with earth and something happened and the bomb detonated. No doubt, this man was subjected to quite a bit of overpressure as you call it, but just by the grace of God, none of the fragments hit him. There's no doubt in my mind that if just one fragment from that bomb had struck this man in any part of his body, being that close, would probably have killed him.

Mr. Broom: I'd like to ask Mr. Settles if he knows of any work being done on extrapolating quantity-distance tables up to the 10 million pound range that he mentioned?

Mr. Settles: Not in the 10 million pound range. I have on my own

attempted to do some extrapolation and I don't know how valid it is. This is simply by the slope of the curve technique.

Mr. Perkins: I'd just like to mention that we have a set of quantity-distance tables that goes to 15 million pounds. It is an official document of the Defense Department and is used for siting of amounts up to these figures.

Mr. Settles: Is this available for dissemination?

Mr. Perkins: Yes, it's a Department of Defense Directive. There is a Directive for location of piers and wharves and shipload quantities of explosives, it's 4145.18, and it has been implemented by the three Services, I don't have the implementation directive. TM 9-1903 for the Army, anyway, it can be made available.

Mr. Endsley: I'd like to comment on the implementation. This is currently in the Air Force Engineers Manual in the 88 series on Piers and Wharves. The Air Force at Ogden Air Materiel Area is currently implementing or developing a table which will go on up into the 10 and 15 million pound range for aboveground situations where the piers and wharves deal with an underground target source. We will be presenting this to the Board for comment, review and adoption for the future.

Mr. Ullian: Again, I refer you to Dr. White for missile damage. Again they claim that 10 ft. per sec. will penetrate the abdominal wall and if I remember correctly, I think equivalent to a 40 ft. drop will bust your head open. And also I'd like to ask Mr. Endsley when will this table be available? We're going to be siting for 10 million pounds of propellant and more within about four months.

Col. Hamilton: Our next subject will be by Mr. Marvin Naron, who is the Facilities Design Branch Supervisor of the Longhorn Division of Thiokol Chemical Corp. He will present 'Pressure and Blast Relief Tests for Building Roofs and Siding,' Mr. Naron.

Mr. Naron: Thank you Mr. Chairman. We of Thiokol Chemical Corporation appreciate the opportunity to attend and participate in these proceedings. The material included in this presentation is not classified.

As noted in the program this presentation will be concerned with pressure and blast relief tests for building roofs and siding. In order to establish the background or necessity for this type of construction, I will briefly describe our operations.

Thiokol Chemical Corporation is the operating contractor for the Army Ordnance Corps of Longhorn Ordnance Works at Marshall, Texas. This facility is presently manufacturing solid propellant rocket motors. The operations involve the hazards common to the industry.

One of the problems yet to be satisfactorily resolved is that which is concerned with the venting or relief of pressure in the event of an incident. Obviously the envelope of a building has to absorb or deflect the elements of nature as well as to satisfy the requirements for performance during an incident.

In order to obtain optimum performance of the materials, the following criteria should be satisfied:

1. Materials should be weathertight.
2. Maintenance costs should be minimum.
3. Missile formation, weight, and size should be minimum.
4. Structural damage to the facility should be limited such that the repairs can be made quickly and easily.

The basic concern in facility planning is optimum personnel protection consistent with efficient and effective production techniques. In an effort to evaluate the characteristic behavior of some of the commercially available construction materials when applied in the established or conventional manner a series of elementary tests have been conducted. These tests were of specific materials and types of construction and as such were not development type studies. Development studies would have indicated or demonstrated the worth of alternate materials and construction.

The first test was designed to evaluate the static load carrying capacity of plastic film type construction which has been used as a blowout or relief panel covering on wood frame wall construction. The plastic film is an 8 mil thickness poly vinyl material. This particular material has reasonable resistence to deterioration by exposure to weather. This test was made primarily to evaluate the load carrying capacity of the typical construction in the event of a pressure build-up without a preceeding fire. A test frame was constructed in a manner similar to the typical construction and was loaded with measured amounts of sand to determine the static load carrying capacity of the film. The primary difference in the test frame construction and the usual construction was that only one film was used in the test set up. In actual practice, a film is placed on both sides of the framing to provide additional protection in the event one film is damaged.

The test panels were made up with a 2 x 4 wood frame to which the film was attached, with 1/2 x 1 1/2" nailing strips. The strips were secured with four-penny nails spaced 8" center to center. In actual construction, the nails are spaced further apart (up to 16"). The film panels were 2' x 4' in size. Each panel was separated by a 1 x 8 frame placed to isolate the panel loading. The panels were simultaneously loaded with measured amounts of sand until failure occurred. The loads varied from 50 to 110 pounds per sq. ft. Failure occurred in a gradual manner in each case. The dynamic load capacity would be much greater, possibly in the 150 to 350 pound per sq. ft. range.

The normal wall construction, especially structures more than single story, are designed for a positive pressure of 10 to 30 pounds per square foot and/or a negative pressure of one half the positive pressure. Roof construction is normally designed for loads approximately one and one half times the wall load depending on the roof slope.

From this you can deduct that the poly vinyl film would cause collapse of the supporting structure.

We have observed at Longhorn the results of poly vinyl film and corrugated cement asbestos applied on adjacent panels. The particular incident was one in which a pressure wave was created without a preceeding flame front. The wall framing covered with film was blown completely out. The wall framing on the adjacent panel covered with corrugated cement asbestos stayed in place even though the frame was damaged. In one instance the wall framing became the missiles and in the other the corrugated cement asbestos became the missile.

The poly vinyl material does perform satisfactorily when a flame front precedes the pressure wave, but not when a pressure rise occurs without a flame front.

The second series of tests were made to compare the pressure relieving characteristics of corrugated cement asbestos board and corrugated fibreglass reinforced plastic siding attached to wood framing. This was done to determine if there were obvious advantages with either material.

These tests were conducted in an unused test area formerly used for static testing of bomb detonators. The structure utilized was an existing concrete structure in the form of a cube bounded on four sides with twelve inch reinforced concrete. The two remaining sides were open. The open sides were closed with wood framing which was covered with the materials tested.

The materials, corrugated asbestos cement and corrugated plastic, were subjected to pressure generated by two sources. One source was an overage rocket motor. This motor contained propellant which when burned would create approximately 170 cubic feet of gas. Under ideal conditions (no heat or pressure loss), this would have created an internal pressure of 11.5 psi within the cubicle. The source was used to simulate a propellant fire within an operating bay or building. The second source used was an overage one pound block of TNT. This source was used to simulate a detonation or high order explosion. Because of the age of the material involved the explosion was not as severe as anticipated.

<u>Report of Damage and Missile Areas</u>

Tests and results are as below:

<u>Test #1</u>

Panel: Corrugated asbestos cement both sides attached to framing with screw type nails.

Pressure Source: Rocket motor

Results: The asbestos cement fragmented when blown free of the framing. The fragments range in size from 1" x 1" to 22" x 36". The major missiles weighing approximately 16 pounds were blown approximately thirty-five feet. The fasteners were either pulled from the framing or sheared at the heads.

<u>Test #2</u>

Panel: Translucent plastic both sides.

Pressure Source: XM-18E3 rocket motor

Results: The plastic was blown free of the framing in complete sheets. There was no evidence of fracture in the sheets. The nail heads were pulled through the plastic sheets. The largest sheet was blown about 65' and weighed approx. 7 pounds.

<u>Test #3</u>

Panel: Translucent plastic (east side), asbestos cement (west side).

Pressure Source: XM-18E3 rocket motor.

Results: The plastic was blown free of the frame with the asbestos cement (transite) remaining intact. The plastic sheets reacted as in Test #2. The largest sheet traveled about 55' and weighed approximately 7 pounds. The two smaller sheets traveled less distance than the large sheet. The fasteners remained in the frame. There were no indications that the transite had started to fail under the pressure. There were no cracks and all fasteners were tight.

Test #4

Panel: Translucent plastic (side), asbestos cement (west side)

Source: One pound of TNT.

Results: The shock wave created by the TNT detonation shattered both panels. The major asbestos cement fragments traveled about 140', and the largest fragment weighed about 12 pounds. The major plastic fragments were blown about 125'; the largest fragment weighed about one pound. The fasteners holding the cement asbestos were pulled from the frame, while the fasteners holding the plastic remained in place. During the performance of the test a brisk wind was blowing which would tend to give the plastic added travel.

The corrugated plastic material apparently is more desirable than the corrugated asbestos cement in that less frame damage should result and the missiles do not weigh as much. It should be noted that the frame in these tests were more rigid than those used in actual construction.

This portion of the discussion will be concerned with observations of damage to building materials and their apparent behavior during incidents at Longhorn. We have observed that poly vinyl film is an excellent material to permit dissipation of pressure created by a fire. The film dissipates or melts quickly and thereby relieves the pressure. The normal firefighting technique of smothering the fire does not apply since the oxidizer and fuel combination does not require additional oxygen to sustain burning. Our problem is to vent the pressure and to prevent the spread of fire to the adjacent construction. The poly vinyl film material does not relieve the pressure as effectively as either corrugated plastic or corrugated cement asbestos. In those cases where the pressure buildup proceeds the flame, the poly vinyl film tends to completely wreck the framing to which it is attached. The framing thereby becomes a missile. Corrugated materials will fracture and leave the framing intact. The fragmented materials then become missiles. Conventional flat roofs with built-up or membrane type roofing does not relieve pressure. Structural steel frames

tend to stay in place during an explosion if the sides and roofs vent or relieve properly. Steam ejector support towers exposed to the direct blast and debris have escaped damage in at least two incidents. This is an indication that the structural frame housing hazardous operations should be structural steel. The formation of missiles of structural steel normally result from the failure of connections due to bolt or rivet shear and/or tension.

The materials which have been tested and/or tried are actually only a small portion of those which are commercially available. The techniques of construction in normal commercial practice have radically changed in the past few years yet the construction material and techniques have not appreciably changed for the rocket industry.

There is a very urgent need for development of techniques and combinations of materials which will satisfy the basic needs as follows:

1. Non-combustible
2. Heat sensitive (dissipate when subjected to flame)
3. Insulating (for comfort and process temperature control)
4. Light weight (inertia of the material to movement causes pressure build-up)
5. Weather tight
6. Basic structural frame should not contribute to the missile hazard

Some possible solutions to the problems might be as illustrated. The structural frame should be all welded construction and anchored sufficiently to develop the full tensile capability of the material.

The effectiveness, economy, and durability of any new technique could be evaluated without an excessive amount of expenditure.

Mr. Broom: I'd like to ask if corrugated aluminum had ever been considered as a suitable material for frangible construction?

Mr. Naron: As such, this would be a personal opinion. I believe that the aluminum unless this swinging panel kind of routine could be worked out, would contribute to the missile hazard, therefore, as such would not be really an acceptable material. However, if a technique of construction could be devised such that the panel would stay attached to the structural frame, that of course is presuming that you can develop a frame that will withstand the forces involved.

Mr. Perkins: I just wanted to remind the people that in the second movie, the large jagged pieces of material flying through the air toward the camera were aluminum sheet off the doors of the cubicle.

This of course was a detonation, you want to keep the separation between burning type incidents and detonation incidents clear in your mind.

Col. Hamilton: Thank you Mr. Naron. Our next subject is 'The Hazard Characteristics of Intermediate Compositions Resulting from the Processing of Composite Solid Propellants.' Mr. McQueen.

Mr. H. F. McQueen, Thiokol Chemical Corp.: This paper describes the first of a series of tests planned by Thiokol Chemical Corporation to better define the hazards of intermediate compositions of solid propellants. The results of these tests, preliminary conclusions, and directions of future tests are also described. The tests were planned following an experimental run in the Continuous Process Pilot Plant when a small amount of 94% solids material was produced. This material exhibited rather unexpected safety chracteristics when compared to standard formulations.

New propellant formulations now in the Development Laboratories will also require extensive testing to determine their production hazards. With these tests and others probably not yet devised, we plan to define as clearly as possible the hazards that occur during processing composite solid propellants.

Present Tests

At the present time the following routine tests are run on samples of propellant during normal processing:

1. Impact sensitivity
2. Auto-ignition temperatures
3. Detonability

The impact sensitivity tester is a machine modified by Thiokol Chemical Corp. from information and tests conducted by the Naval Ordnance Testing Laboratories.[1] This uses a 5 lb. ram and an impacter assembly. Results are evaluated by the Bruceton Method developed by the Naval Explosive Research Laboratory.[2] HMX is used as the reference standard.

[1] Thiokol Chemical Corp., Explosive Ordnance Section Impact Sensitivity Tester, Project 571, 15 August 1959.

[2] NAVORD Report #4236, 16 March 1956.

Auto-ignition tests are conducted on 10 gram samples in a close-temperature control oven rather than a Woods metal bath. This method produces more reproducible results than does the molten metal bath with our propellants, and is considered more safe.

Detonability tests are performed on both confined and unconfined samples at several temperatures. Tests for critical diameter are run on experimental propellants.

Friction and static electricity tests are not ordinarily run on routine propellant production, however, they were performed on the hi-solids samples. The friction tester is similar to the device used by Rocketdyne wherein a metal disc is rotated on a sample contained in a Teflon cup.[1] The disc is rotated by the spindle of a small drill press. Sufficient data has not yet been accumulated on this friction tester to completely evaluate the results in comparison with other propellant formulations.

Propellants Tested

During an experimental run of a continuous process pilot plant a small amount of material of approximately 94% solids was produced. When this was tested, it indicated some unusual characteristics and it was decided that a series of tests should be run on various formulations of hi-solids propellants.

Tests were outlined on eleven different mixes where in the fuel to oxidizer ratios were varied maintaining a constant aluminum to binder ratio. In order to prepare these ratios with the least risk a 20 gallon mixer with remote controls was temporarily installed in the Destruct Area at the Wasatch Plant. No provisions were made for circulation of water for temperature control.

Four mixes have been made to date having the following approximate compositions:

Total Solids	Oxidizer	Al	Binder	Fe_2O_2 Catalyst
90	78.5	11.4	10	0.06
92	82.8	9.1	8	0.04
94	87.1	6.9	6	0.03

During the remainder of the paper they will be referred to simply as 90, 92, 94% mixes. From these mixes samples were prepared for detonability and low energy hazard testing. The compositions listed above

[1]Report R-4069, Potential Hazards in Rocketdyne Quickmix Process.

were selected based upon the possible compositions the Continuous Process Pilot Plant could accidentally produce. That is, a constant aluminum to binder ratio with increasing amounts of oxidizer. The iron oxide was being used as a catalyst in the particular experimental formulation when the incident occurred in our pilot plant.

The detonation tests indicated critical diameter, minimum booster, transition from burning to detonation and projectile impact. The critical diameter tests determine the minimum diameter that will sustain a detonation for at least 4 charge diameters, or 6 diameters in the fractional pipe sizes. The minimum booster tests determine the amount of explosive necessary to initiate a sustained detonation in the propellant charge one inch larger than the critical diameter. The projectile impact tests determine the projectile of minimum kinetic energy that will detonate the sample propellant.

High Energy Hazard Tests

a. Critical Diameter - See Table #1

90% Solids - One critical diameter test was conducted on an 8" schedule 40 pipe 32" long. A pentolite explosive booster and a #8 blasting cap were used to initiate the propellant. A one inch thick steel witness plate and seismic equipment were used to monitor the test. The results showed that the 90% solids material will not sustain detonation under these conditions. A considerable equivalent explosive force was registered, however, which indicates the critical diameter for this material is slightly in excess of 8 inches, estimated at 10 inches. As the diameter of the barrel of the Ko-Kneader involved in our incident was 8" we limited the critical diameter tests for the first phase at this diameter. Future tests are planned on this formulation.

92% Solids - Only one sample was tested during this series. This was a charge contained in a 4" schedule 40 pipe 24 inches long with a 2 inch diameter by 2" long pentolite booster for initiation. The results showed this propellant will detonate under these conditions.

94% Solids - Confined tests. Seven samples were loaded into schedule 40 pipes of 2, 1-1/2, 1-3/4 and 1/2" diameters and a minimum length to diameter ratio of four. A pentolite booster was used to initiate all the tests except for the 1/2" where a small RDX booster was used. A 1/2" steel plate was used to witness the detonations.

A detonation was recorded on all samples except the 1/2" charge diameter. Since this composition detonated in the 3/4" diameter it is assumed the critical diameter when confined in a schedule 40 pipe is between 1/2" and 3/4".

TABLE I

CRITICAL DIAMETER TESTS
FOR
HI-SOLIDS PROPELLANT

Percent Solids Propellant	Propellant Charge (inches) Confined	Unconfined	Explosive Booster	Results
94	2 dia x 8 long		1 1/2 dia x 1 1/2 long Pentolite (71 gms)	D
94	1½ dia x 8 long		1 1/2 dia x 1 1/2 long Pentolite (71 gms)	D
94	1 dia x 8 long		1 1/2 dia x 1 1/2 long Pentolite (71 gms)	D
94	½ dia x 8 long		3/4 dia x 3/4 long Pentolite (10 gms)	F
94	3/4 dia x 8 long		3/4 dia x 1 1/2 long Pentolite (20 gms)	D
94	3/4 dia x 24 long		3/4 dia x 1 1/2 long Pentolite (20 gms)	D
94	½ dia x 8 long		1/2 dia x 3/4 long RDX	F
94		3 dia x 22 long	1 1/2 dia x 1 1/2 long Pentolite (71 gms)	D
		2 ¼ dia x 16 long	3/4 dia x 1 1/2 long Pentolite (20 gms)	D
92	4 dia x 24 long		2 dia x 2 long Pentolite (164 gms)	D Seismic equipment measured approx 20 lbs TNT equivalent
90	8 dia x 32 long		3 dia x 4 long Pentolite (762 gms)	Deflagration, some propellant burned. Seismic equipment recorded approx 40 lbs TNT equivalent

NOTE: D = Detonation F = Failure
Approximate Density of Propellant = 0.04 lb.in.^{3}

94% Solids - Unconfined. Two unconfined tests were conducted, one a three inch diameter x 22" long charge and one 2-1/4" x 16" long charge contained in cardboard tubes. Pentolite boosters were used for initiation with 1/2" steel witness plates. As a sustained detonation occurred on both tests, it is evident the unconfined critical diameter of this formulation is less than 2-1/4 inches. Further tests will be made to define this more closely. Complete results shown in Table 1.

b. Minimum Booster Tests - See Table #2.

Ten tests were conducted on the 94% solids material for minimum booster. Eight of these were conducted with propellant confined in schedule 40 pipes of 1, 2, and 3" diameters and two with the charges unconfined in 3" and 2-1/4" cardboard tubes. Pentolite boosters and one or more #8 blasting caps were used for initiation. The confined tests showed that a detonation can be induced in a 3" diameter by one, #8 cap and in a 2" diameter by six, #8 caps. In the 2-1/4" unconfined charge detonation was induced by a 3/4" dia. x 1/4" long pentolite booster.

c. Burning to Detonation Transition Tests - Table 3

Seven tests were conducted on 94% solids material to determine its characteristics and possible change from burning to detonation. Black powder and pyrotechnic squibs were used to ignite the surface of propellant. Steel plates were used to witness any detonation. The tests showed that in a 3" charge diameter, the 94% solids material will go very rapidly from burning to detonation. On two tests the transition was so rapid it appeared to detonate directly from the squib, this could be detected using framing cameras or other techniques which are planned on future tests.

d. Projectile Impact

Two tests have been conducted by projectile impact on the 94% solids propellant. The first test consisted of throwing a 4-3/4" diameter x 1/2" steel plate at an 8" schedule 40 pipe of the material. Total energy contained in the plate was 285 kilogram calories which resulted in a high order detonation. The second test consisted of firing a 30 caliber rifle bullet into an 8" diameter x 12" long propellant charge. The kinetic energy[1] here was approximately 0.772 kilogram calories which resulted in a low order detonation.

[1]See "Science of High Explosives", Dr. Melvin A. Cook, for methods of measurement and calculations.

TABLE II

MINIMUM BOOSTER TESTS
HI-SOLIDS PROPELLANT

Percent Solids Propellant	Propellant Charge (inches) Confined	Unconfined	Explosive Booster	Results
94	3 dia x 8 long		3/4 dia x 3/4 long Pentolite (10 gms)	D
94	1 dia x 8 long		3/4 dia x 1 1/2 long Pentolite (20 gms)	D
94	1 dia x 8 long		3/4 dia x 3/4 long Pentolite (10 gms)	D
94	2 dia x 8 long		3/4 dia x 1/4 long Pentolite (3 gms)	D
94	2 dia x 8 long		4 No. 8 Blasting Caps	F
94	2 dia x 8 long		6 No. 8 Blasting Caps	D
94	1 dia x 8 long		3/4 dia x 1/4 long Pentolite (3 gms)	D
94		3 dia x 22 long	3/4 dia x 1 1/2 long Pentolite (10 gms)	D
94		2 ¼ dia x 16 long	3/4 dia x 1/4 long Pentolite (3 gms)	D
94	3 dia x 18 long		1 No. 8 Blasting Cap	D

NOTE: D = Detonation
F = Failure
Approximate Density of Propellant = 0.04 lb/in.^{3}

TABLE III

HI-SOLIDS PROPELLANT
TRANSITION FROM BURNING TO DETONATION TESTS

Percent Solids Propellant	Propellant Charge (inches) Confined	Explosive Booster	Results
94	3 dia x 18 long	2 oz. blk. powder & Squib	Burned for approx. 30 sec. then detonated.
94	6 dia x 28 long	2 oz. blk. powder & Squib	Detonated without burning
94	3 dia x 18 long	2 oz. blk. powder & Squib	Detonated without burning
94	3 dia x 18 long	¼ oz. blk. powder & Blasting Cap	Burned for approx 1/2 sec. then detonated.
94	4 dia x 20 long	207-A Squib	Detonated without burning
94	3 dia x 18 long	207-A Squib	Detonated without burning
94	2 dia x 8 long	207-A Squib	Deflagration - a small amount of propellant was left on the witness plate

NOTE: Approximate Density of Propellant = 0.04 $lb/in.^3$

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Low Energy Hazard Tests

a. Impact Sensitivity

Twenty samples for each propellant formulation of 90%, 92%, 94% solids were tested for each temperature of 80° F, 120° F, and 150° F, and in each of the cured and uncured states. In general as the temperature increases, the impact sensitivity increases or the impact drop height decreases. These formulations do not show any significant differences from the normal impact characteristics of standard Thiokol propellants. See Table IV and accompanying graphs.

b. Auto-Ignition

Thirty-two samples were tested on each of the cured 90, 92, and 94% solids materials. The one hour auto-ignition points ranged from 360° F to 402° for these samples. At 540° F all the samples ignited in 6 to 8 minutes. With the exception of the last batch of 94% solids material, the one hour temperature decreased with the increase in per cent solids. The second batch of 94% solids had a one hour ignition point of 402° F. Future tests are planned to explain this anomaly. Thirty-two samples of uncured material were also tested. The one hour auto-ignition points ranged from 385° F to 397° F showing a different trend from that of the cured samples. See Table IV. At 450° F all the samples ignited in 2 to 8 minutes.

c. Friction Tests

Sixty tests were conducted on the 90, 92, and the first batch of 94% solids cured propellant. Lack of test fixtures prevented tests on the remaining 94% material. The results indicate that the higher percentage propellant takes less time to initiate. At 1250 RPM it takes a longer period to initiate than at 2370 RPM but the material explodes violently at the slower speed. At 2370 RPM, the sample burns and has a less violent reaction. Similar results were experienced on the uncured samples. See Tables V, VI, and VII.

d. Static-Electrical Discharge

Five static discharge tests were conducted on each of four hi-solids samples both cured and uncured material. The samples were subjected to the discharge from a 0.01 microfarad condensor charged to 24,000 volts. Under these conditions none of the 40 samples fired. Numberous holes were cut in the propellant by the arc. See Table IV.

TABLE IV

HAZARD CHARACTERISTICS OF INCREASED SOLIDS PROPELLANT

Propellant	1 Hr. Auto-Ignition	50% Explosion Impact Sensitivity 80° F	120° F	150°F	Static Electrical Discharge
		Cured			
90%	389°F	24.4	20.82	20.75	No Fire
92%	370°F	24.0	20.6	20.82	No Fire
94%	360°F	24.4	22.9	20.0	No Fire
94%	402°F	24.1	25.7	22.0	No Fire
		Uncured			
90%	391°F	11.65	10.5	10.0	No Fire
92%	395°F	13.15	12.4	13.25	No Fire
94%	397°F	24.8	21.4	24.7	No Fire
94%	385°F	26.1	20.6	22.7	No Fire

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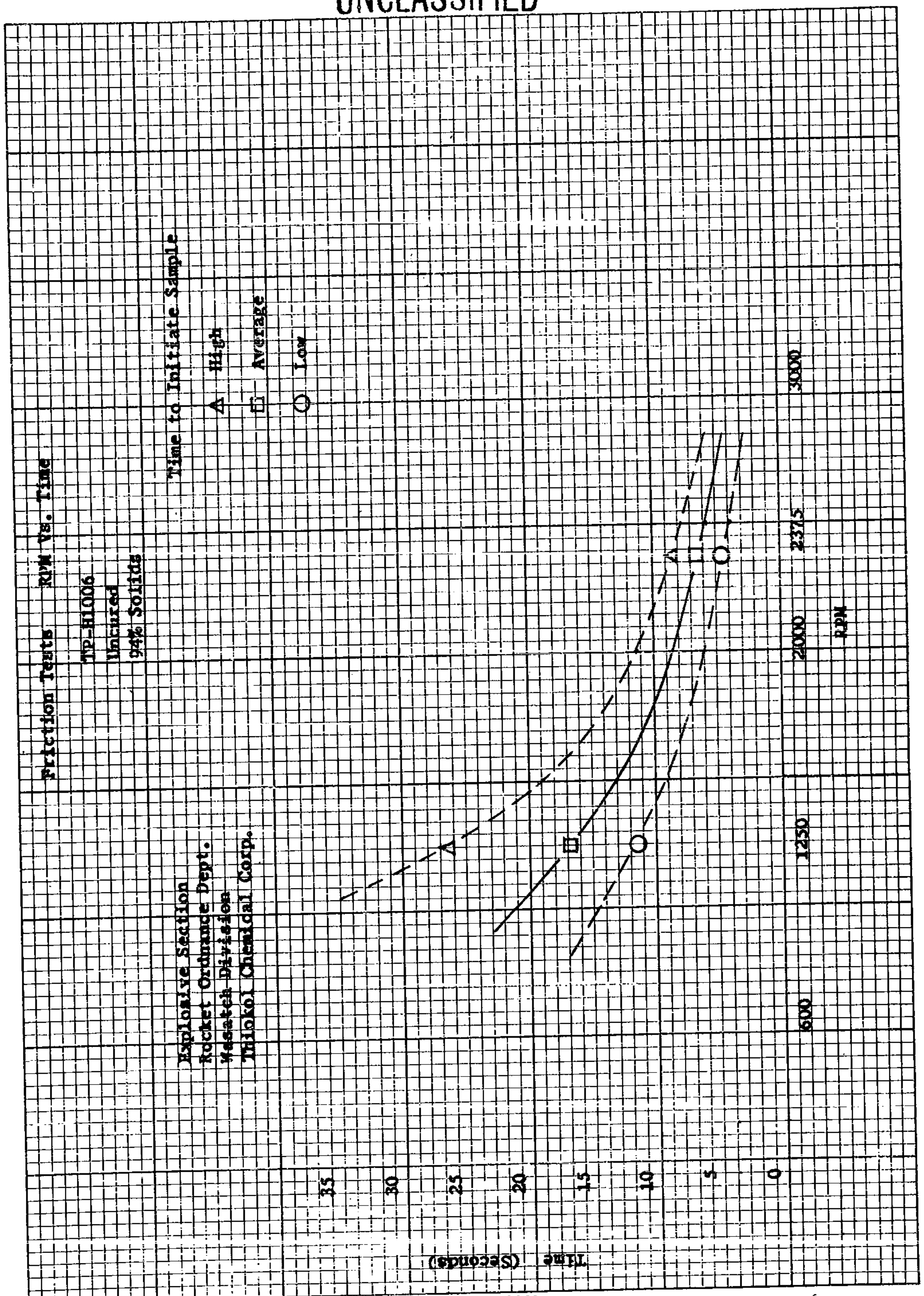

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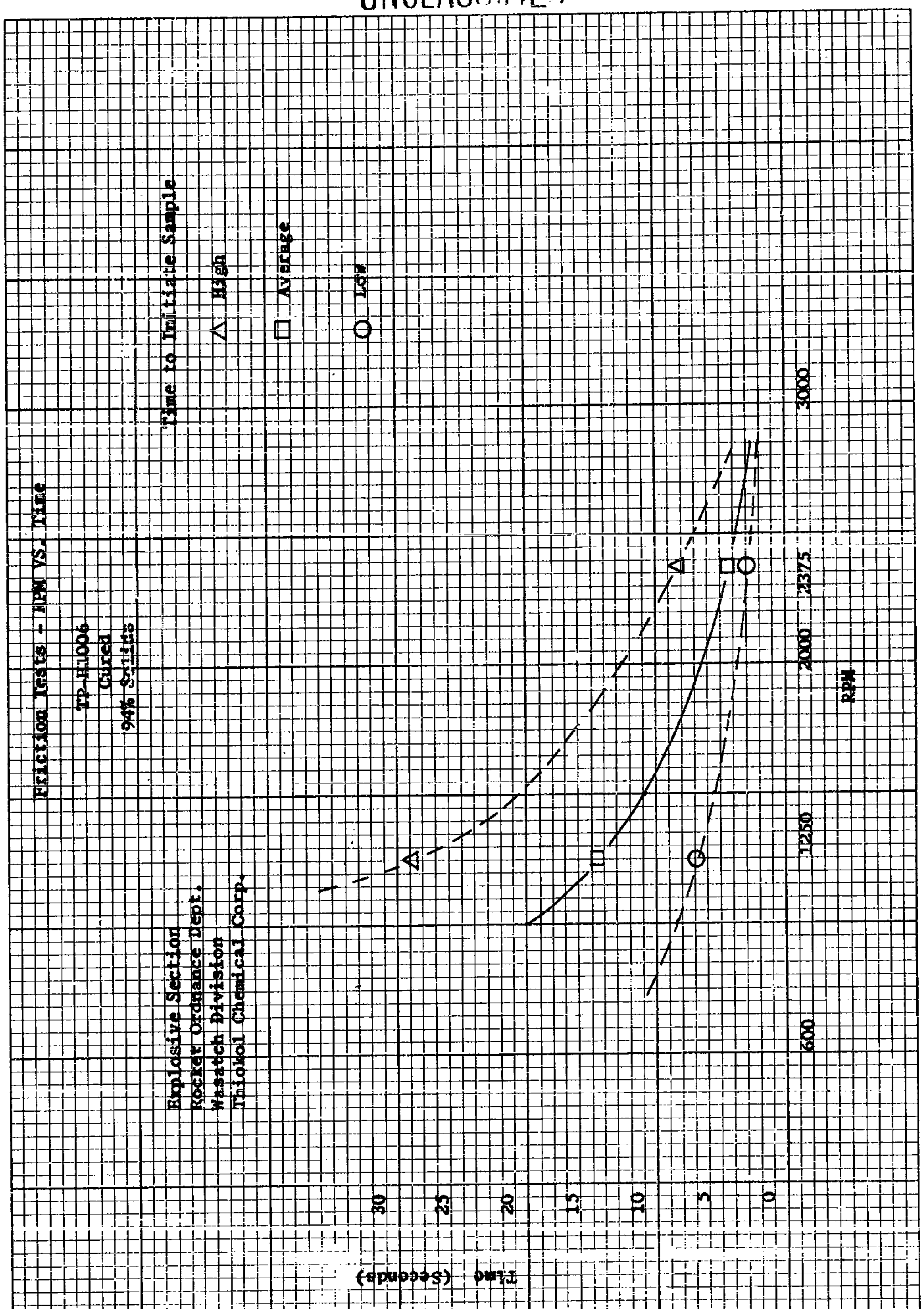

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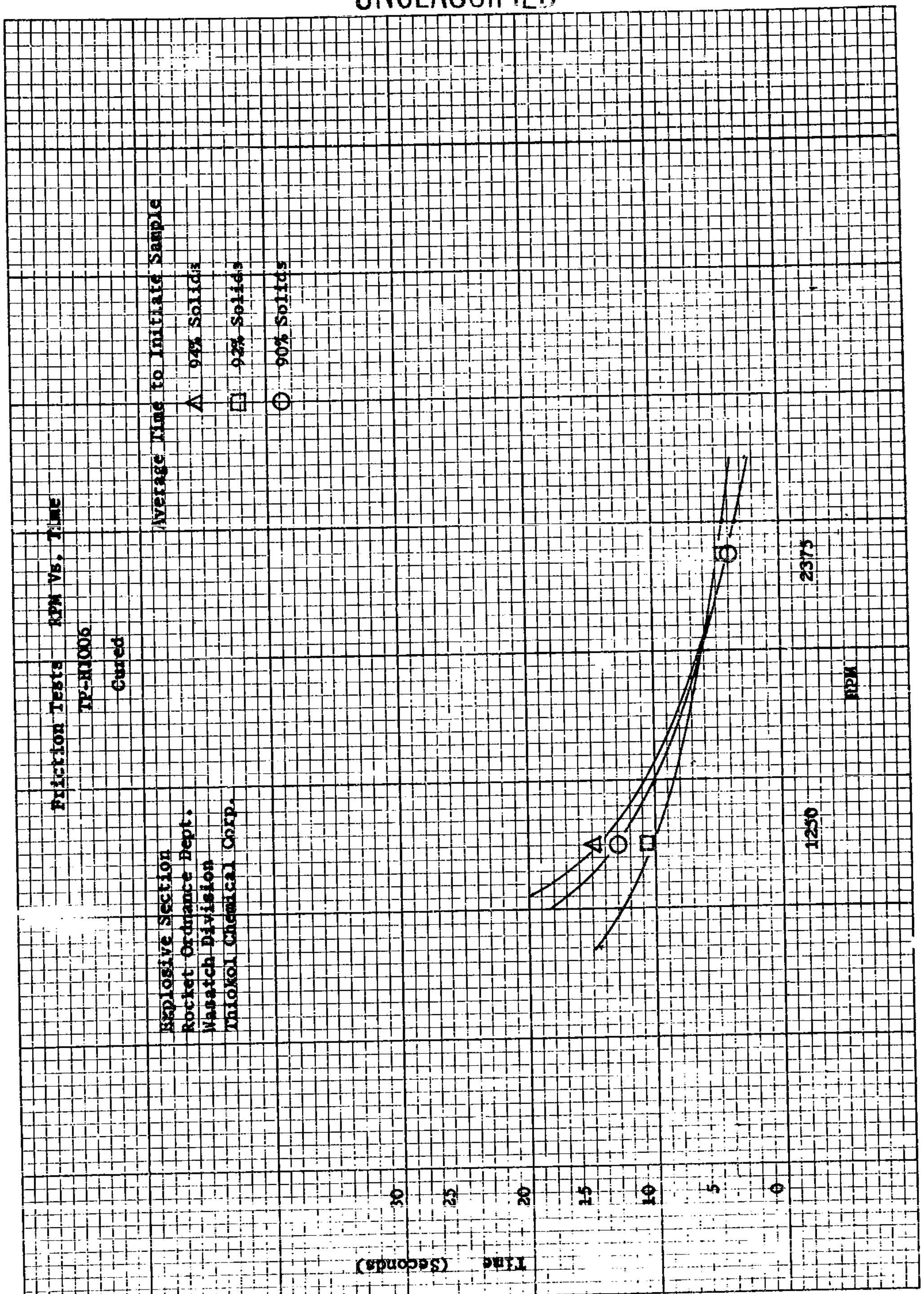
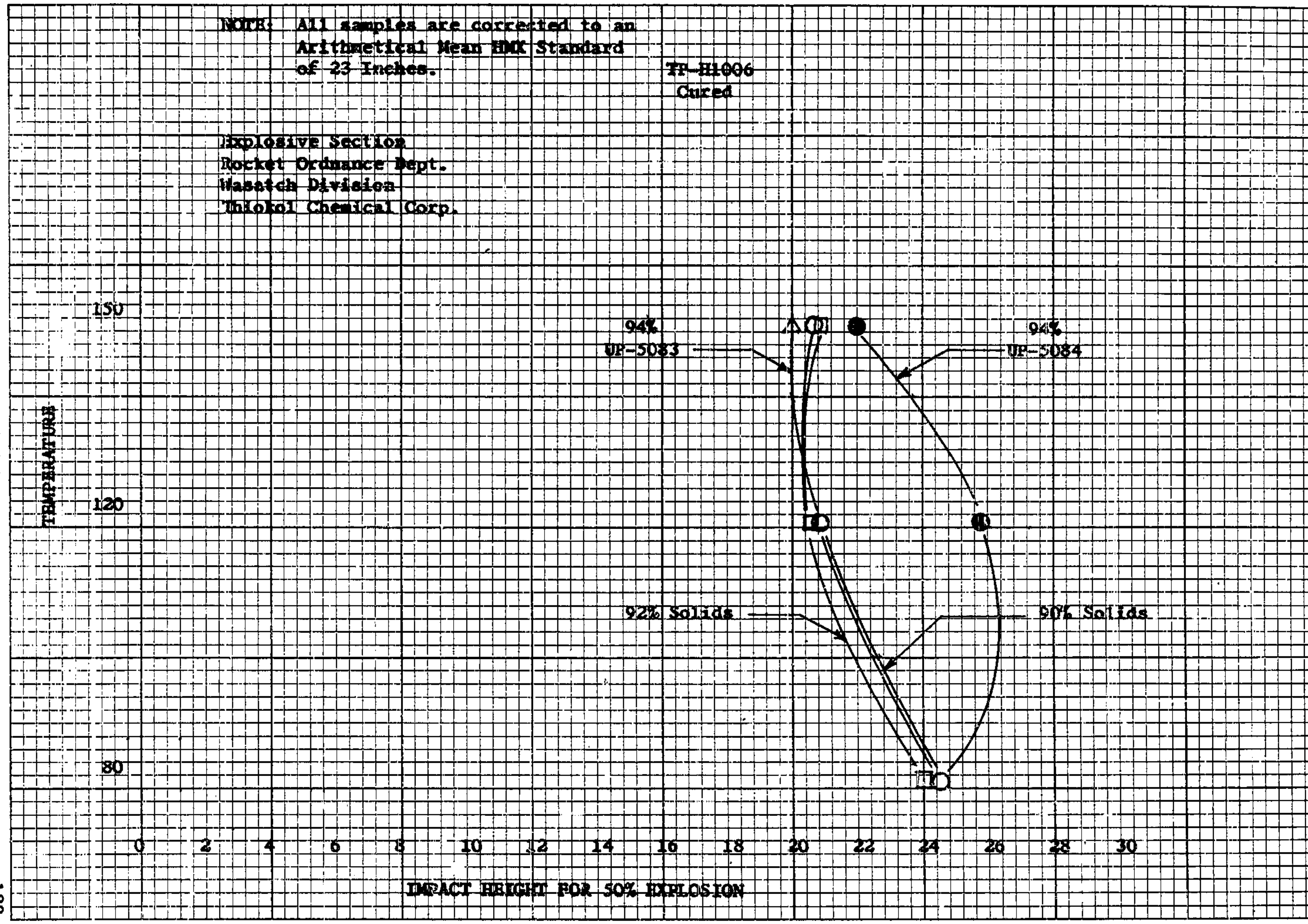

Friction Tests RPM Vs. Time
TP-H1006
Cured
Average Time to Initiate Sample
94% Solids
92% Solids
90% Solids
Explosive Section
Rocket Ordnance Dept.
Wasatch Division
Thiokol Chemical Corp.
Time (Seconds)
30
25
20
15
10
5
0
1250
2375
RPM


NOTE: All samples are corrected to an
Arithmetical Mean HMX Standard
of 23 Inches.
TP-H1006
Cured
Explosive Section
Rocket Ordnance Dept.
Wasatch Division
Thiokol Chemical Corp.
94%
UP-5083
94%
UP-5084
92% Solids
90% Solids
TEMPERATURE
150
120
80
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
IMPACT HEIGHT FOR 50% EXPLOSION

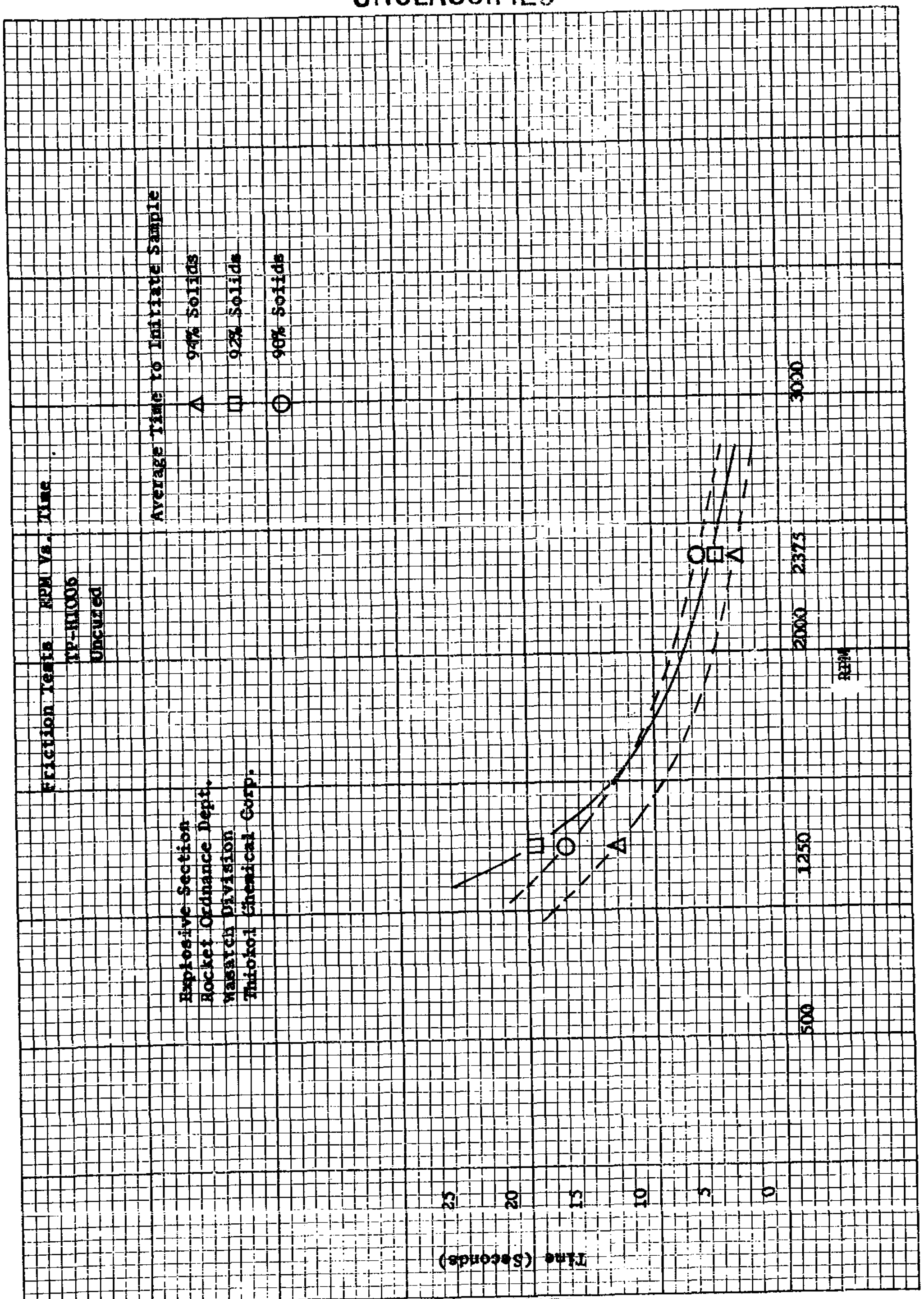

Friction Tests RPM Vs. Time
TP-H1005
Uncured
Average Time to Initiate Sample
△ 94% Solids
□ 92% Solids
○ 90% Solids
Explosive Section
Rocket Ordnance Dept.
Wasatch Division
Thiokol Chemical Corp.
500
1250
2000
2375
3000
RPM
25
20
15
10
5
0
Time (Seconds)

TABLE V

HI-SOLIDS PROPELLANT
FRICTION TESTS
90%

RPM	CURED Result	CURED Time to Fire	UNCURED Result	UNCURED Time to Fire
2371	Detonated	4.5 sec.	Some burned &	4.0 sec.
"	Burned	4.25 sec.	some detonated	2.5 sec.
"	"	5.5 sec.		2.5 sec.
"	"	4.25 sec.		3.5 sec.
"	"	4.0 sec.		5.0 sec.
"	"	3.75 sec.		3.0 sec.
"	"	5.75 sec.		2.5 sec.
"	Detonated	4.0 sec.		5.5 sec.
"	Burned	3.5 sec.		4.5 sec.
"	"	4.0 sec.		3.0 sec.
	Average -	4.3 sec.	Average -	3.6 sec.
1254	Detonated	23.5 sec.		14.0 sec.
"	"	9.25 sec.		13.0 sec.
"	"	14.0 sec.		16.0 sec.
"	"	11.0 sec.		14.0 sec.
"	"	11.25 sec.		9.0 sec.
"	"	15.0 sec.		14.5 sec.
"	"	12.0 sec.		18.0 sec.
"	"	12.5 sec.		13.0 sec.
		8.75 sec.		9.0 sec.
		15.0 sec.		9.0 sec.
	Average -	13.2 sec.	Average -	12.95 sec.

TABLE VI

HI-SOLIDS PROPELLANT
FRICTION TESTS
92%

	CURED		UNCURED	
RPM	Result	Time to Fire	Result	Time to Fire
2371	Burned	6.0 sec.	Most of these samples burned & some detonated	7.0 sec.
"	"	4.5 sec.		5.5 sec.
"	Detonated	5.0 sec.		3.5 sec.
"	"	4.0 sec.		6.5 sec.
"	"	4.0 sec.		6.0 sec.
"	"	4.0 sec.		3.5 sec.
"	"	6.0 sec.		6.0 sec.
"	"	4.5 sec.		4.5 sec.
"	"	3.0 sec.		6.0 sec.
"	"	3.5 sec.		4.5 sec.
		Average - 4.4 sec.		Average - 5.3 sec.
1254	Burned	12.0 sec.		37.0 sec.
"	"	13.0 sec.		29.0 sec.
"	"	12.0 sec.		18.0 sec.
"	Detonated	6.0 sec.		11.0 sec.
"	Burned	12.0 sec.		11.0 sec.
"	Detonated	11.0 sec.		24.0 sec.
"	Burned	11.0 sec.		9.5 sec.
"	Detonated	11.0 sec.		18.0 sec.
"	"	8.0 sec.		24.0 sec.
"	"	9.0 sec.		12.0 sec.
		Average - 10.5 sec.		Average - 19.25 sec.

TABLE VII

HI-SOLIDS PROPELLANTS
FRICTION TESTS
94%

	CURED		UNCURED	
RPM	Result	Time to Fire	Result	Time to Fire
2371	Detonated	8.25 sec.	Burned	4.5 sec.
"	"	5.5 sec.	"	8.0 sec.
"	"	3.5 sec.	"	5.5 sec.
"	"	4.25 sec.	"	6.5 sec.
"	"	3.5 sec.	"	7.5 sec.
"	"	4.0 sec.	"	6.5 sec.
"	Burned	4.5 sec.	"	5.0 sec.
"	Detonated	3.0 sec.	"	6.5 sec.
"	"	3.0 sec.	"	7.5 sec.
"	"	3.5 sec.	"	8.5 sec.
	Average -	4.3 sec.	Average -	6.6 sec.
1254	Detonated	8.75 sec.	Detonated	13.5 sec.
"	Burned	8.5 sec.	"	15.0 sec.
"	Detonated	7.0 sec.	"	20.5 sec.
"	"	7.5 sec.	"	15.0 sec.
"	"	9.0 sec.	"	18.0 sec.
"	"	18.0 sec.	"	26.5 sec.
"	"	21.0 sec.	"	14.5 sec.
"	"	26.0 sec.	"	16.0 sec.
"	"	29.0 sec.	"	17.0 sec.
"	"	15.0 sec.	"	11.5 sec.
	Average -	14.9 sec.	Average -	16.75 sec.

NOTE: In the last five tests conducted on cured propellant at 1254 RPM, a Teflon pin was used instead of wood.

Future Work

As a result of these tests future tests are being planned where the formulations are changed to increase the ratio of aluminum to oxidizer and to include other burning rate catalysts for their effect. As these tests become more standardized and background data is accumulated, it is proposed to expand the number of tests run on each new formulation produced by our Development Laboratories. Other tests are being considered on possible hazardous gases formed during vacuum mixing and casting by decomposition of perchlorate on other materials. A complete audit of all plant processes has also been started to measure or estimate the potential energies available for the ignition of an incident.

Conclusions from these very preliminary tests are that extreme care must be used in processing composite solid propellants. There are gaps in our knowledge and experience of the intermediate compositions produced during mixing that may represent hazards not previously recognized.

Mr. L. C. Walther, Aerojet-General Corp.: I would like to comment on something Mr. McQueen touched on lightly. Aerojet has had quite a bit of experience in this area of trying to investigate the hazard characteristics of intermediate steps in our process and one of the checks which we have now instituted prior to use of the R&D formulation in the production plant is the evaluation of reaction gases which are generated as a by-product of any of our binder or oxidizer constituents. Going back to about four years ago, 1957 specifically, we had three large explosions at our plant where we concluded that two of these were initiation either electrostatically or mechanically thru friction of a gaseous mixture which was a reaction by-product of one of the amine binder constituents and the oxidizer. Since then we have continued in this investigation area andnnow as I said instituted this evaluation of any gaseous or liquid by-products of our reaction and we now feel that this is a very important safety check of our formulations prior to use.

Mr. McQueen: I might comment on that a moment. In the system that I just described the hydrocarbon binder system is fairly neutral and therefore there is to the best of our knowledge, no reaction between this binder system and the ammonium perchlorate generating in the ammonia. However, in certain of our operations, either in deaeration or in vacuum casting, we know that we remove an organic volatile component and we are quite concerned now about our vacuum lines. We have evidence that this volatile component will come over in the vacuum lines and will condense then in the vacuum pump. We were concerned about its characteristics from a flash-back. So far we have no evidence that it is hazardous but it's one of those things

that we have been overlooking for some time. And the other is that for the first time we have observed, in vacuum casting, traces of ammonia and relating this to your experience four years ago, we've gotten quite concerned about it.

Dr. Ball: I'd first like to compliment Mr. McQueen on the type of work that he has reported here. I think this is very important and I would also recommend that everyone else here as a means of finding out what causes trouble, the only thing I might suggest is that this kind of work be done before the facts instead of after. Secondly, I'd like to inquire if you have positively excluded any casual effect of foreign bodies. Do you know for sure that you had nothing in there that didn't belong? So many times in failures of mechanical equipment of this sort, we ultimately find out that something got in our work that didn't belong there, a piece of gravel or metal or something.

Mr. McQueen: I'm sure from your experience you know that after an incident the post-mortem is very difficult unless you had a high-speed movie coverage of the incident itself. Unfortunately, unlike post-mortem of a rocket engine malfunction or a test stand where you have it well instrumented for just that sort of thing, we don't have that and it's very difficult from what remains to assess what was the cause. Now I think you can say in Thiokol's history, we feel that over 90% of our incidents were caused by metal metal friction either from a foreign object or from equipment mal-function. In the particular incident to which I referred, reviewing the data indicates there was indeed a foreign object or an equipment malfunction because the mixer had stalled and the operators did not recognize the condition and attempted to start it under a stalled condition. But we were unable to find anything from the subsequent post-mortem we could say 'this was it.' The point I perhaps didn't make and I'll take this opportunity to make it, is in the manufacturing operations, we've all been concerned because of this with "how do we make the equipment," "how do we eliminate these known hazards associated with friction as safe as possible," whereas perhaps we're overlooking some conditions such as the hazardous gases so we're now going back and trying to assess not only possible equipment malfunctions or sources of foreign material, sources of friction, but how about chemical compositions. And then the next point, which again I didn't cover too well, but which we are quite concerned about, how do you duplicate these conditions with standard tests. Impact sensitivity means nothing to a mixer.

Mr. A. Heeseman, Grand Central Rocket Co.: Have you established any impact value of either raw material or finished propellant that you will not process in your production operations?

Mr. McQueen: No, in fact I think I covered that just now. We can no way relate impact sensitivity to the conditions that exist in our plant. Our composition proved more sensitive on the impact tester than HMX but I assure you I'd much prefer to process our composition than I would HMX. So the answer is no.

Mr. Hirsch: I was wondering if you have run any card gap sensitivity tests or similar tests with these I3AA formulations that sustain detonation in your critical diameter tests?

Mr. McQueen: Yes, the tests I referred to were card gap tests and in reviewing the number of slides I had last night, I decided I had about 26 too many but if you care to I'd be glad to show you the results of these card gap tests. Of the finished formulations up to 88% total solids, we were unable to cause a sustained detonation. As you probably know, you've observed the tests on the full scale stage 1 engine.

Dr. Ockert: First of all, I want to add my compliments to those of Dr. Ball on the thoroughness of your investigation. With regard to the samples on which you ran detonability with very high solid loading as over 90%, you got positive detonation results with these, did you not?

Mr. McQueen: At 90% we got a contribution but not a sustained detonation as determined by the framing camera. At 92 and 90 we did, yes indeed.

Dr. Ockert: Were these cured or uncured?

Mr. McQueen: Both.

Dr. Ockert: What do you know about the state of consolidation on them?

Mr. McQueen: Very poor.

Dr. Ockert: This was what I wanted to know. Thank you.

Mr. Visnov: If you will recall, you asked me that question about the ammonium perchlorate plus hydrocarbon systems?

Mr. McQueen: Yes.

Mr. Visnov: Now that I have thought it over and had an opportunity, I may have a few leads for you to follow. There has been some work both by the British and in this country on the thermal decomposition of ammonium perchlorate. The class of work by the British, the authors are Bircumshaw and Newman. Copies are widely available in this country. I believe it's a Confidential report. Also, Aerojet and Thiokol both have programs on the development of high temperature resistant propellants and in thes programs they had to go into the

temperatures at which ammonium perchlorate plus organics decomposed. In general, I would estimate that in any auto-ignition temperature, the prime mover is the choice of oxidizer. I haven't seen any case where a binder when it's added to the ammonium perchlorate will increase the auto-ignition temperature and both of these pieces of work, both programs, showed instances when you add a hydrocarbon to ammonium perchlorate you will decrease the auto-ignition temperature. One of the products I suspect the finger should be pointed to is if your organic degrades. If there is any moisture formed as one of the decomposition products, this may generate trouble because you get perchlorate ions there and as an analogy we might remember that a couple of the most ferocious explosions in this country have taken place in the electro polishing field where aluminum is electro polished in a mixture of perchlorate acid and organic anhydrides. I believe in both instances several city blocks were cleaned off. One in Chicago and I believe one in Los Angeles. But here was a case where perchlorate acid plus an organic was used and I believe this lead may throw some light on the choice of a solid oxidizer or ammonium perchlorate when moisture gets into the act.

Mr. McQueen: Well, as I stated earlier, I'm a processing man and am concerned about increases in sensitivity or decreases in auto-ignition temperature of hydro-carbon ammonium perchlorate systems, let's say in curing. Now in the ammonium nitrate systems where the nitrate is not properly stabilized, we know that you'll get free acid and the auto-ignition temperature will go down to the point where you'll have auto-ignition at room temperature. I think a lot of people here have had experience with oven fires with ammonium nitrate. But I was not aware of anyone who had any difficulty with ammonium perchlorate hydro-carbon systems. The one possible exception would be American Potash in pure ammonium perchlorate where it became contaminated from the equipment with cupric salts. So that was what prompted the question.

Mr. Visnov: I believe that the addition of copper in its forms has been deleterious to the ammonium perchlorate life, it's a little hairy proposition here. Again, on this Bircumshaw & Newman piece, they showed that if you add ammonium salts, this is one thing which may increase the thermal stability of ammonium perchlorate but this is purely in laboratory work and not in the processing field.

Mr. Lowrey: We also have been very much concerned about the meaning of some of these tests and some of our physical chemists have done a theoretical analysis of the drop test and this might shed some light for you on a comparison of various materials and their sensitivity from the drop test and what it may mean as far as heat is concerned.

Mr. McQueen: Do you have any published report by JANAF or do I go through channels?

Mr. Lowrey: I think if it's not in our last report it will be in our next report, in a physical chemistry section.

Mr. McQueen: Relating impact tests to real conditions that exist in a plant?

Mr. Lowrey: He analyzed using heat transfer equations for the rate of heat transfer away from the hot spot that was generated in a specific locale in the propellant and assumed a certain amount of kinetic energy that had been transferred to this spot and calculated the temperature and the effect of this temperature, i.e., the rupture of a bond of some sort, and this bond of course would be different depending upon which material you were talking about, whether it was a nitrate or a composite or whether it was a chlorinated material. The amount of energy that would be released when such a bond was broken assuming that it would react or non-react depending upon what the proximity was to this particular material, then using computers he calculated whether the heat could be dissipated fast enough from this particular source to stop the reaction in which case he would not get a shot or in the case where the heat was not dissipated fast enough through heat transfer, he would get a heat build-up which would cause detonation which in this case would lead to a shot on the drop test.

Mr. McQueen: This then would be a correlation between the friction test and the operating conditions. Did you say you can correlate the impact test?

Mr. Lowrey: We were essentially analyzing the impact test to see exactly what the significance of the impact test was, or we were trying to, because we thought that the impact test by itself, if it is just an empirical test, it doesn't help as much. But if we can take the fundamental chemical structure of the material and correlate the drop test with this fundamental chemical structure, then we can predict what the sensitivity will be for any unknown composition before we even run a drop test. Actually for various compositions, we've been able to predict what the drop test would be and then we run the drop test and check it. For certain standard materials we've been coming real close.

Mr. Levens: For those who may be interested in information about the decomposition of anhydrous perchloric acid or perchloric acid in electro polishing solutions and also an unclassified report by Bircumshaw, Phillips, & Newman on ammonium perchlorate thermal decompositions, I refer you to Chapter 11 in the ACS Monograph 146 published in 1960 on the subject of perchlorates.

Dr. Ball: I want to add a little emphasis to a point that you have already made sir, which is that you have identified in your equipment a composition in which you can produce ignition of that composition you have to predict everything else that has happened. The unsolved problem you have is finding out how you got that ignition but the rest of the thing is from a safety standpoint, points to a situation and also to an attack on the possible cure.

Mr. McQueen: In this light I'm personally quite interested in hearing your report on the ABL incident.

Col. Hamilton: Thank you very much Mr. McQueen. The next item on the agenda is by Mr. Higgins who is responsible for Facilities, Planning and Safety for Rocket Power, Inc. He will discuss 'Preplanning Safety and Efficiency into a Propellant Process Plant.'

Mr. W.J. Higgins, Rocket Power Inc.: Confronted by the numerous problems found in solid propellant chemical processing due to temperature and humidity control and also the inherent dangers and the excessive costs in the handling of explosives, the selection of the site location and the type of facilities is of the utmost importance. Climatic conditions must be considered and climatological data had to be evaluated.

Rocket Power, Inc. decided on a site in the isolated and picturesque rolling desert area of the Salt River Valley near Mesa, Arizona where the climatic conditions appeared to be the most desired (Figure 1). The average daytime relative humidity in the Salt River Valley is 30 per cent. There are two separate rainfall seasons. The first occurs during the winter months from November to March when the area is subjected to storms from the Pacific Ocean. The second rainfall season occurs during July and August when Arizona is subjected to widespread thunderstorm activity, whose moisture originated in the Gulf of Mexico. The spring and fall months are generally dry, although precipitation in substantial amounts has fallen on occasion during every month of the year.

Beginning with June the summer weather is hot, with thundershowers in the evening. The change from the heat of summer to mild winter temperatures occurs during October. Night-time winter temperatures frequently drop below freezing during the three coldest months. Considering these unusual climatological conditions in the Salt River Valley as well as the inherent problems from occasional excessive humidity, the air conditioning system to be selected would be required to operate continuously. An inside temperature of 80°F is maximum when the outside temperature reaches 110°F. An inside temperature of 70°F is minimum when the outside becomes 25°F. An inside relative humidity has to be maintained less than 40%

UNCLASSIFIED

ROCKET POWER/TALCO SOLID PROPELLANT PLANT
MESA, ARIZONA

FIGURE 1

UNCLASSIFIED

for all air conditioned areas. All other areas are greater than 40% or less than 60%.

Rocket Power, a subsidiary of The Gabriel Company of Cleveland, Ohio, manufactures sled rockets, sounding rockets, booster rockets, infrared emitters, starter cartridges, igniters, pilot seat ejection systems, production custom loading of solid propellants and "propellants for tomorrow" at this facility.

This plant of unique design was planned by the combined efforts of Mr. C. E. Bartley, President of Rocket Power, and Mr. Frank A. Marion, Executive Vice President. Mr. Bartley was the receiver of the 1953 Hickman Award for outstanding contributions to the field of solid propellants, former President of Grand Central Rocket Co. and former Chief Engineer of Solid Rockets at the Jet Propulsion Laboratories of the California Institute of Technology. Mr. Marion has had many years of experience in the architectural design of explosives and solid propellant plants. The results of this vast experience produced a solid propellant processing plant that insured economical construction through modular design, employee safety and efficient manufacturing and maintenance operations.

Unlike other explosives manufacturing plants that isolate their hazardous operations into widely separated buildings, Bartley and Marion decided to incorporate more steel and concrete into two structures, set paralleled to each other, separated only by one hundred and fifty feet of open area. These buildings are identified as Line 1 and Line 2 (see Figure 2). Maximum use was made of fire-retardant materials. Over 6,000 yards of concrete went into the construction, averaging one truckload of cement an hour, eight hours a day for sixty days. Had the plant been constructed in isolated buildings, it would have spread over 500 acres of land. The expense of installing the inter-building roads and utilities for such a facility alone would be much greater than the cost of this new type of plant.

Line 1, consisting of 33,000 sq. ft. of floor area, was constructed to house hazardous tasks into operating cells with their necessary remote control rooms, as well as to provide rooms for the various service departments, such as receiving, inspection, stores, lunchroom, chemical laboratory, production control, X-ray, inert assembly operations and shipping.

The service departments are separated from the operating cells by remote control rooms (see Figure 3) which act as main building corridors. These corridors are lined on both sides with 12" concrete and steel reinforced walls stressed to withstand 5,000 pounds of explosives. These walls add extra safety to all operating and

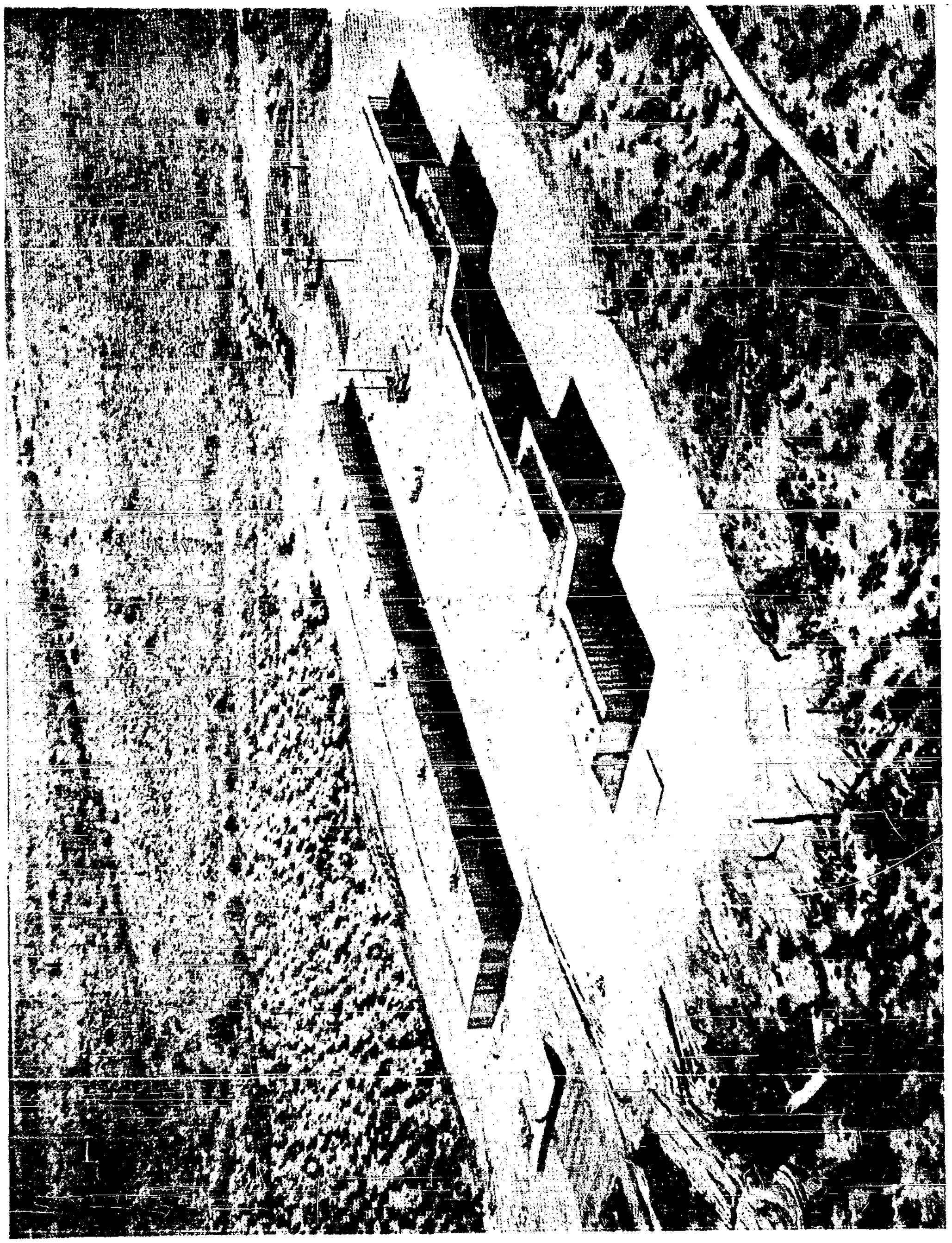


FIGURE 2

UNCLASSIFIED

FIGURE 5

service personnel. All hazardous operations in the operating cells are remotely controlled from these rooms. All the operating cells, measuring 15x20' are equipped with steel fire and escape doors. These doors were provided for limiting the spread of fire from bay to bay or room to room. The outside walls of the operating cells are of the blow-out type, made up of 2" of cemetos board with emergency knock-out panels.

Line 2 was planned to house the most hazardous operations, such as: chemical (oxidizer) classifying, grinding and weigh-out; propellant mixing, casting, curing; environmental, tool pulling, final assembly, static firing test stands and control rooms. This building of 30,000 sq. ft. has an earth fill covering 5' above the roof in certain areas and a 30' embankment in addition to heavily reinforced concrete walls (see Figure 2). All the walls throughout the plant are considered structural walls.

The ceilings throughout the plant are 12' high and roof slabs are 8" thick reinforced concrete with a covering of white stone. Preplanned air conditioning duct holes were placed in the roof over each operating cell and support room throughout Line 1 and in certain rooms and cells in Line 2 (see Figure 4). There are no windows in the plant.

The selection of an air conditioning system to meet the most exacting requirements was necessary. Humidity, temperature and air movement had to be controlled within each operating cell, control and support room, independent of each other.

The installation of a centralized cooling or heating duct system could not be used because of possible incidents whereby toxic gases could readily contaminate the entire plant.

All operating cells in the plant had to have explosion proof air conditioning equipment, explosion proof thermostats, and off and on switches. The supply air fans for these cells had to be located outside the air stream, and the air stream must be free from all switches or other electrical devices which may cause sparking or arcing. All mechanical equipment is located on the roof over each room (see Figure 5). When the system is operating in any room, the supply air fan must be in operation. Non-explosion proof installations were installed for non-hazardous rooms. Automatic changeover thermostats are located in each conditioned room together with thermostats, on-off switches, as well as an automatic-manual fan selector switch. To prevent tampering with the thermostat control setting, it is located near the equipment on the roof. Once it is set, the room temperature is automatically controlled. A minimum ventilation of 10 cfm per

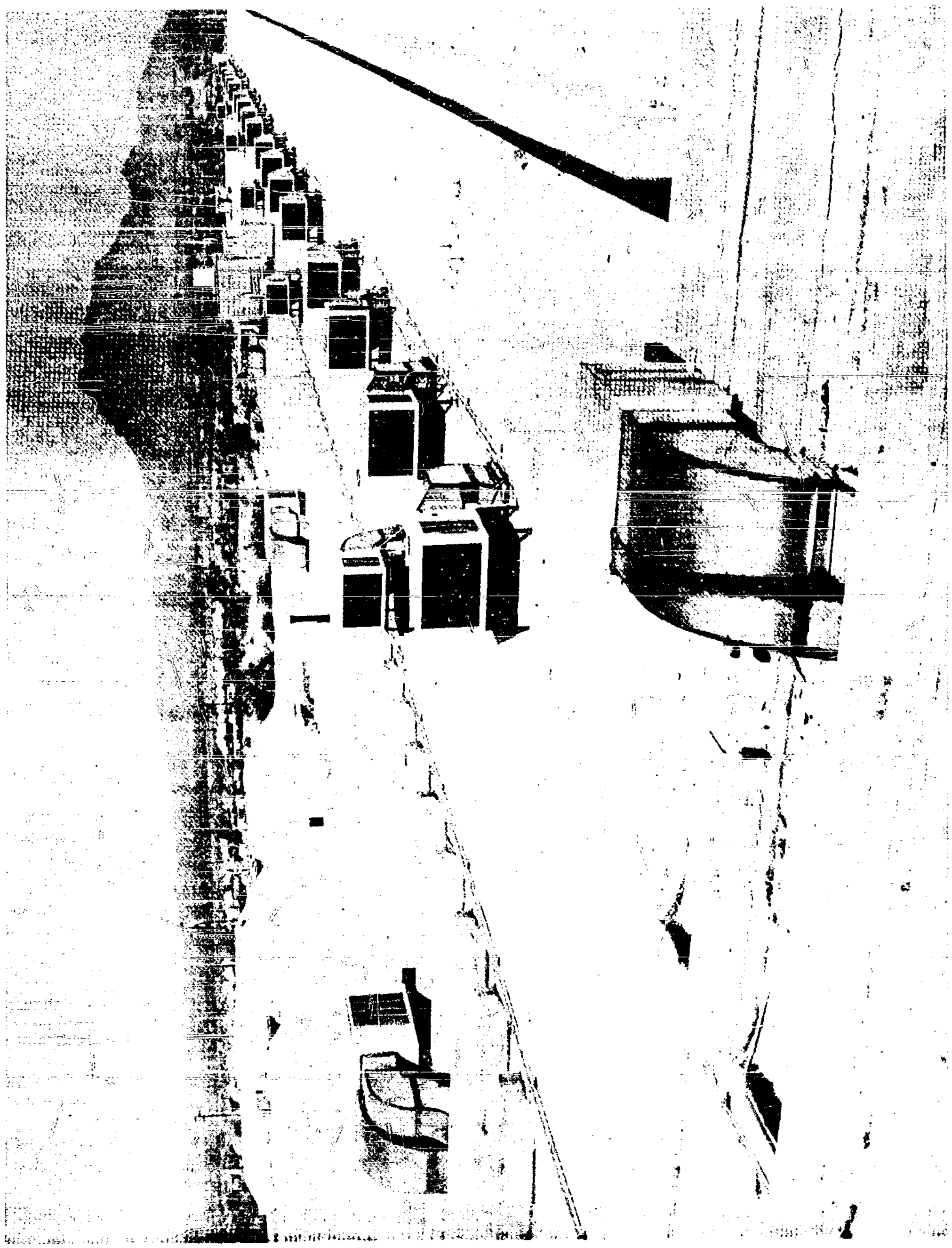


FIGURE 4

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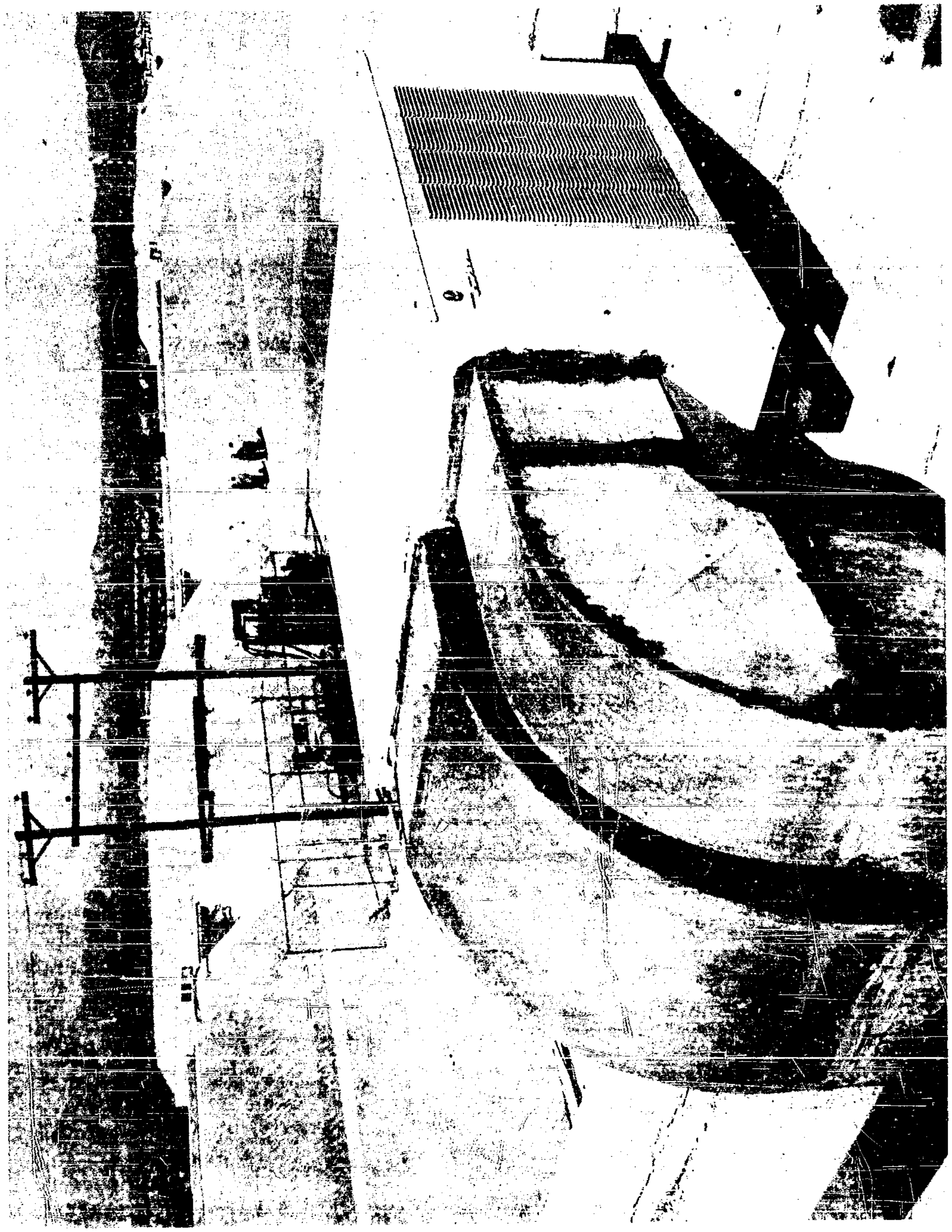


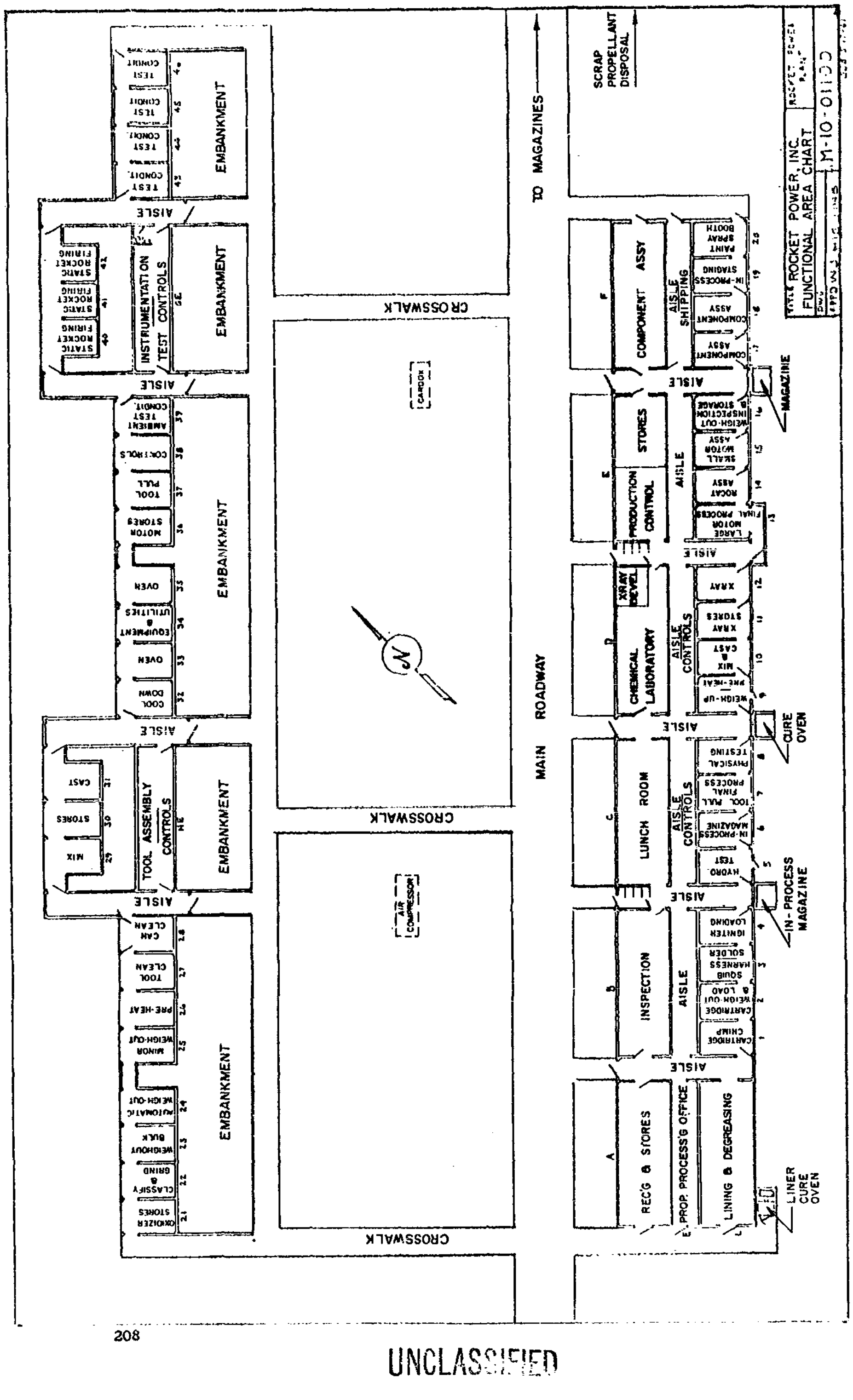
FIGURE 5

UNCLASSIFIED

person or 50 cfm per system is required in every cell or room. Supply and return air in the operating cells is not interconnected with that of another cell. The conditioning equipment is complete with automatic defrosting controls, automatic defrosting reverse valve, automatic changeover thermostat and supply air fan control to prevent discharge of below room temperature air during heating or defrosting operation. Each system is sized so that no supplementary electric resistance heating is required. All the equipment is UL approved.

The ducting system was fabricated from galvanized steel. Recommendations of the American Society of Heating and Air Conditioning Engineers were followed with respect for duct sizing, velocity of air movement, metal gages, fittings, etc. The locating of the air conditioning units directly over the cells or rooms served permitted the installation of ducts through the center of the roof of each cell or room. The supply air grills are of the double deflection type. The return air grills are the stamped face type (see Figure 6). The fiber glass air filters are located in the return air stream of the conditioning equipment on the roof. The Searles Refrigeration Co. of Phoenix was awarded the air conditioning contract and the Henderson Electric Co. of El Monte, Calif., was given the electrical contract. The installation problems were of no consequence as the duct inlets were preplanned in the building design. The air conditioning system was completed over a 45 day period after issuance of the contract. Installation costs amounted to $42,216.00 including maintenance for one year.

The type of equipment selected was the Mathes Heat Pump-Summer and Winter Air Conditioners and the Mathes Packaged Air Conditioner. These units were manufactured by the Mathes Co. of Fort Worth, Texas. The Mathes Heat Pump were selected because its operating costs are far below the average. Mathes Heat Pumps have an extremely high Coefficient of Performance (COP) and do not require supplementary electrical resistance heat. This reduces operating costs considerably. All heat pumps operate on the same basic principle. During the cooling cycle, the unit absorbs heat from the air inside the building and transfers that heat to the outside. During the heating cycle, the unit absorbs heat from the outside air and transfers that heat to the inside. When the outside temperature is near freezing, or below, and there is considerable moisture in the air, the outside coil of the heat pump may become covered with frost. This is entirely normal in the operation of the heat pump, when on the heating cycle. If this blanket of frost begins to reduce operating efficiency too much, the unit will then go into a defrosting cycle automatically. The fan in the outdoor unit does not operate during the defrost cycle, and usually, the blower fan in the indoor unit will shut off automatically a few seconds after the cycle begins to prevent circulation of cool air.


ROCKET POWER, INC.
FUNCTIONAL AREA CHART
TO MAGAZINES
SCRAP PROPELLANT DISPOSAL
MAIN ROADWAY
CROSSWALK
EMBANKMENT
AISLE
TEST CONDIT.
STATIC ROCKET FIRING
INSTRUMENTATION TEST CONTROLS
AMBIENT TEST CONDIT.
CONTROLS
TOOL PULL
MOTOR STORES
OVEN
EQUIPMENT & UTILITIES
COOL DOWN
MIX
STORES
CAST
TOOL ASSEMBLY CONTROLS
CAN CLEAN
TOOL CLEAN
PRE-HEAT
MINOR WEIGH-OUT
AUTOMATIC WEIGH-OUT
BULK WEIGHOUT
CLASSIFY & GRIND
OXIDIZER STORES
COMPONENT ASSY
SHIPPING AISLE
PAINT SPRAY BOOTH
IN-PROCESS STAGING
MAGAZINE
STORES
PRODUCTION CONTROL
WEIGH-OUT INSPECTION & STORAGE
SMALL MOTOR ASSY
ROCAT ASSY
LARGE MOTOR FINAL PROCESS
XRAY DEVEL
CHEMICAL LABORATORY
AISLE CONTROLS
XRAY
XRAY STORES
MIX & CAST
WEIGH-UP PRE-HEAT
CURE OVEN
LUNCH ROOM
PHYSICAL TESTING
FINAL PROCESS
TOOL PULL
IN-PROCESS MAGAZINE
HYDRO. TEST
INSPECTION
IGNITER LOADING
SQUIB SOLDER HARNESS
CARTRIDGE WEIGH-OUT & LOAD
CARTRIDGE CRIMP
REC'G & STORES
PROP. PROCESS'G OFFICE
LINING & DEGREASING
LINER CURE OVEN
AIR COMPRESSOR

SUMMARY SPECIFICATIONS

MODEL	24HAH - HP	38HAH - HP	62HAH - HP
Cap. BTU/Hr* - Rated in accordance with ARI Standard 240-57			
Cooling	22500	32000	55000
Heating	24000	33000	56000
Total Power Consumption (watts)	3150	4370	7480

This installation is compact, adaptable and economical, and it consists of the following units:

(38)	- 24 HAH HP	- 2ton heat pumps	
(3)	- 38 HAH HP	- 3ton heat pumps	
(6)	- 62 HAH HP	- 5ton heat pumps	
(2)	- 24 HAH	- 2ton - cooling only units	
(1)	- 62 HAH	- 5ton - cooling only units	
TOTAL		124 tons of controlled air conditioning	

Bases and stands for the Mathes equipment were furnished by the contractor.

The heat pump air conditioning system which recirculates the air from the cell or room through the conditioner back into the room necessitates close dust controls. Therefore, the operations that make excessive dust, such as oxidizer weighout, handling and grinding, are provided with localized vacuum type exhaust systems. These systems are used only when the machinery is in operation. The plant's compressed air system provides the method for creating the necessary vacuum exhaust. Air is piped into a three inch galvanized metal tube downstream from the intake vent. When the compressed air is turned on, it creates a vacuum at the intake, operating similar to a venturi tube. This inexpensive exhaust system is very effective and safe as there are no moving parts. The dust is exhausted into a glass filter bag or into a wet barrel located outside the plant.

The control of toxic chemical dust is another problem. At Rocket Power our difficulties do not arise so much from dust entering a working area, thereby contaminating parts or assemblies, but from the necessity of containing the chemicals within a confined area. This problem was solved through the use of glove boxes, performing operations whenever possible within these compartments.

The results obtained from this air conditioning system have made the Rocket Power solid propellant processing plant an ideally climatized facility, both for the employee and for the chemical processing operations. A study of the indoor plant temperatures over a one year period revealed that there is a variance of two or three degrees above or below the required 77° average temperature. Humidity, which is a major problem in propellant processing, has presented no problem here. Although normal desert air is relatively dry, summer and winter rains are often heavy. This type of equipment proves itself at such times.

The type and installation of electrical equipment and wiring conforms to the National Electrical Code and is in accordance with the regulations as outlined in Section 7, ORDM 7-224.

Conductive floors are provided in all areas and at all operations where explosives are exposed. The operating areas as well as the traffic lanes are covered with a prepared aluminum floor finish (Gilmore and Nolan's - Grey Aluminum Epoxy Floor Finish - Epoxzol #6890). This conductive floor covering dissipates the static charge over a wide area. Tests of these treated floor surfaces have revealed that the electrical resistance measured between ground and a 5 pound electrode in direct contact with 5 square inches of floor area to be far below the maximum of 250,000 ohms. (Ref. 705 - ORDM 7-224)

An analysis of the solid propellant processing operation revealed that 58% of the process time was consumed in material handling. (Figure 2) The multi-bay type of construction of this facility permits shorter travel between operations thereby improving the safety factor and decreasing the handling costs. Overhead conveyors were installed over certain operations, utilizing air operated motors, for raising and lowering rocket motors. The material handling equipment has been designed to reduce to a minimum the handling of individual rocket motors.

Weld plates were prepositioned in all ceilings above Operating Cells for the installation of overhead conveyors or hoists.

Waste materials and scrap propellants are disposed of in our specially designed burn-out pits. These pits of unique design eliminate the need for using costly electrical squibs and the inherent dangers when using squibs for igniting the scrap.

The use of butane gas, flame thrower type burner in conjunction with an electrical spark plug, permits the remote firing of scrap. The system is so designed to prevent any possible accident. The operator must return to the control area before he can throw the

switch and valve to ignite the charge. A wind sock is provided for determining wind direction prior to burning.

In process storage magazines are placed in certain operating cells to permit straight line flow of rocket motors. These magazines are posted with maximum limits for personnel and explosives. An underground storage magazine placed at proper intraline distance is provided for the storage of completed rocket motors, cartridge actuated devices, etc. All items stored are placed according to the compatibility regulations as outlined in ORDM 7-224.

Security chain link fence, 7' high, surrounds the complete facility. Entrance is by the main gate only. The reservation is posted every thousand feet along the perimeter warning of the dangers.

A public address system is installed throughout the plant and operated by the security guard at the main entrance gatehouse. During static test firings this system is under the control of the Test Control Operator for the "Count Down" and "All Clear" signals.

The air compressor is located in the open yard area between the two lines. Compressed air lines and outlets are installed throughout the main corridors of the plant. This air is used universally for operating tools, machinery and equipment, vacuum type exhaust systems and vacuum cleaning machines. Each operating cell is equipped with eight 1" utility inlets from the main corridor.

Water standpipes, located in accessible yard locations, with water under good pressure, serve for extinguishing rubbish or brush type fires. These standpipes are equipped with 50' of fire hose.

No fires are fought in any of the bays, corridors or rooms containing rocket motors, cartridges or other explosives. The fire-retardent materials used in construction of the facility and the incorporation of strategic fire doors eliminate the necessity for the use of a sprinkler or deluge system. Fire extinguishers are placed where needed for electrical, paper or rubbish fires. Production lines are laid out in such a manner that a fire in one area will not shut down the whole plant.

Good housekeeping is the order of the day in all departments at all times. Air operating (water type) vacuum cleaners are used for cleaning up hazardous areas. All yard areas are cleared of brush. Fire lanes have been placed outside the plant perimeter fence. All matches, lighters, etc. are removed from all personnel entering the plant. Smoking is permitted in the lunchroom only with safety type electrical lighters provided for this purpose. Areas where no explosives are permitted are posted.

Our plant has been in operation for approximately two years and for the year 1960 we were fortunate to receive the National Safety Council Award for the first division in Maricopa County "Lowest Accident Frequency Rate." It is felt that the pre-planning effort for built-in safety has contributed greatly towards achieving this record.

Col. Hamilton: Thank you very much Mr. Higgins. Mr. Hugh Richards who is a member of the Technical Staff of United Technology Corp., a subsidiary of United Aircraft, will discuss 'Anticipated Problems in Processing Large Booster Units.'

Mr. Hugh Richards, United Technology Corp.: Thank you Col. Hamilton. Gentlemen. The United Technology Corporation, during the past two years, has designed, built and operated a development facility for the pilot production of large segments for use in booster units. During the past eight months this facility has been actively engaged in subscale experimental segmented motor work and scale up of tools and processes for large segment work. The successful firing of several subscale segmented rocket motors, each containing about 3,000 pounds of propellant established the feasability of joint design used in assembling the segments into a single motor. Recently two large units have been processed. The first of these was a physical properties vehicle containing some 30,000 pounds of propellant and a three segment motor having a total propellant weight of approximately 70,000 pounds. The center segment of this latter motor contained approximately 60,000 pounds of propellant. This motor was static-fired last Saturday.

With this experience as a background, I would like to discuss some of the safety problems we anticipate in processing propellant for single segments weighing 100,000 pounds and more.

First, since many of you have not had the opportunity of seeing the UTC Development facilities, I would like to take a few minutes to describe them. The facility is located on 3200 acres of remote land, approximately 15 miles southeast of San Jose, California. Figure 1 shows an overall view of the development facility. Starting from the bottom of the photograph and proceeding up the main road is the Administration Building, Receiving and Inspection, Hardware Preparation, and the Maintenance Building. At the end of the main road on the right are the Medium In-Ground Ovens and on the left the Large In-Ground Oven, where casting and curing operations for large segments are performed. The facility shown in the upper left of the photograph is Oxidizer Processing, which houses the drying, blending and grinding operations. Below the Oxidizer facility is the 200 gallon Horizontal and 150 gallon Vertical Mixer facilities. The Static Firing facilities can be seen on the center-right of the photograph.

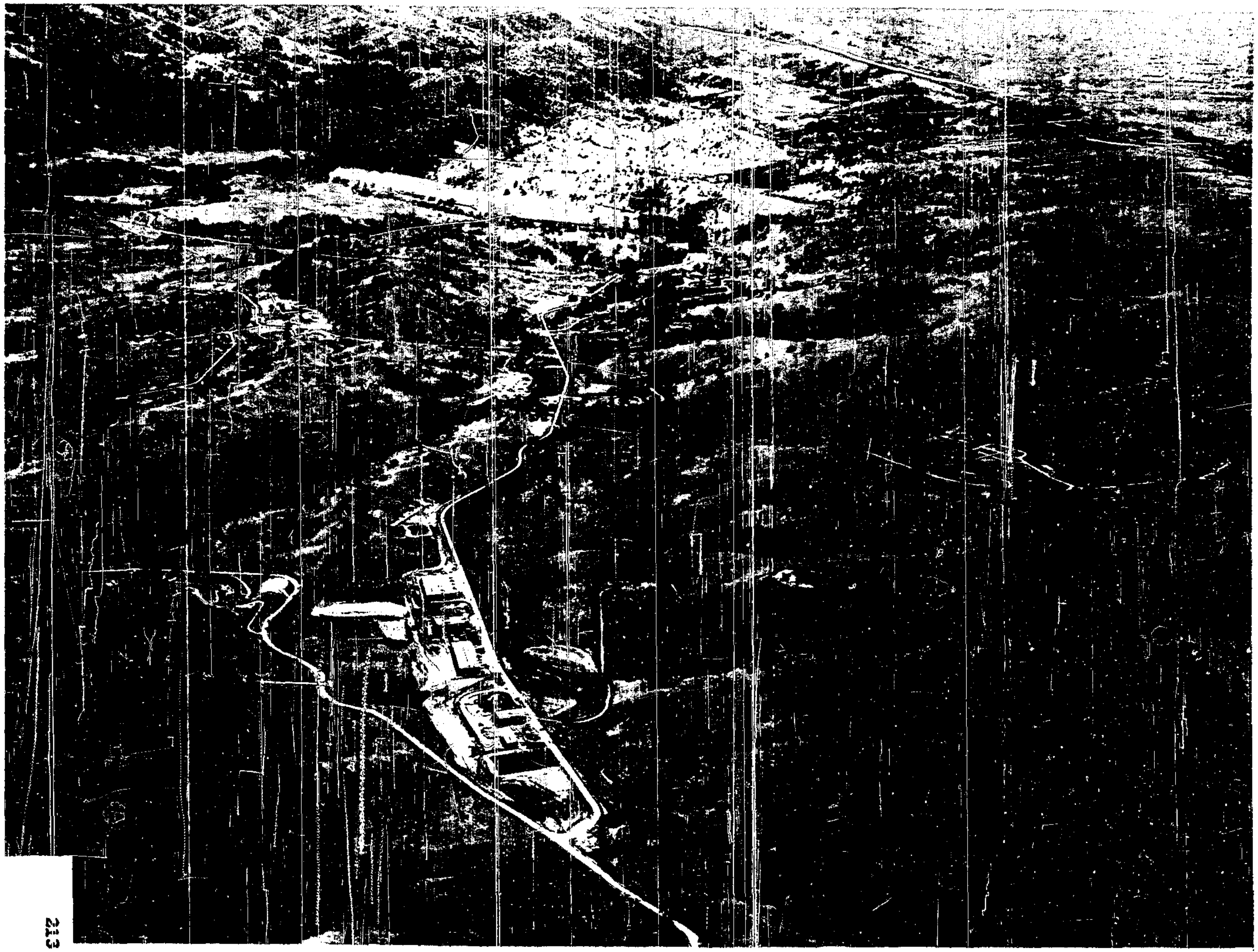


Figure 1.
United Technology Corporation's
Development Center

To better acquaint you with the facility and those operations involved directly with the processing of propellant for large segments, we have prepared a short film which I would like to show at this time.

(The film was narrated during its presentation. The details of oxidizer preparation, propellant mixing, propellant acceptance testing, casting and static firing are shown and discussed.)

In reviewing the processing of large segments, as compared with the processing of small units of perhaps 500 pounds, we find little difference in the operations except in casting, curing and subsequent operations. Preparation of oxidizer, fuel and mixing are essentially the same with the exception that these operations continue over an extended period of time. It is in the extended use of equipment that we can anticipate our first problem with safety of operation. In the operation of equipment on a 24-hour basis for days at a time there will be the problem of constant surveillance of proper maintenance, equipment checkout and housekeeping. The mixing operation, in particular, must be closely studied to assure that the desire for production over an extended period of time does not take precedence over the meticulous attention to safety required in this operation.

Both the 200 gallon horizontal and 150-gallon vertical mixing facilities at UTC are designed such that the mixing operation is completely remote from the introduction of oxidizer into the fuel through the draw-off propellant in the case of the 200-gallon horizontal, and the removal of the mix can from the 150-gallon vertical mixer. Draw-off of propellant from the 200-gallon horizontal mixer is accomplished by remotely activated bottom discharge valves. At UTC we have found that the 150-gallon change can vertical mixer, because of its construction, can be operated at substantially higher production rates with enhanced safety features over the 200-gallon horizontal mixer.

We anticipate that, through refinements in facility design and processing improvements, we will be able to further increase the production rate of both the vertical and horizontal machines, although we feel the vertical machine has the greater potential.

Since the mix can for the vertical mixer is also the casting vessel, there is very little clean-up necessary at the mix station. Also, since the vertical mixer has no submerged packing glands, it is capable of being operated for extended periods with lesser maintenance.

We have also found that by premixing all of the propellant ingredients except the oxidizer and final curative, at the fuel preparation facility, we can greatly decrease the mix time at the final mixing facility. The premix can be qualified for acceptance prior to final mixing and will help to assure better reproducibility from batch to batch and thus enhance both the safety of operation and control of quality.

A rather interesting phenomenon was found to occur during our high speed mixing studies with the 150-gallon vertical mixer. These studies were conducted in an attempt to increase production by using higher than normal blade speeds. The cavitation of propellant, as evidenced by a void between the mixer blade and the propellant, was found to occur. At an outer agitator speed of 45 rpm the blade moves propellant away from its surface at a much faster rate than the propellant can flow. Although the cavitation can be heard and we have made limited measurements to determine vibration effects, we are not at this time sure of the real significance or effect of this cavitation. One of the things which concerns us is the proper selection of blade speed for the larger vertical mixers, such as the 300 gallon. Because of the larger pot diameter the larger machines generally run at higher rpm with resulting high peripheral tip speeds which may tend to increase the cavitation effect. We expect to begin a rather extensive program to study the effect of cavitation on mixing and the bearing system of the mixer.

In the processing of oxidizer we find that it would be desirable to use much larger containers for handling. Within the near future we expect to convert to the use of tote bins and perhaps use new conveying methods.

In the loading of large segments which contain many batches of propellant, the role of acceptance testing prior to casting becomes one of extreme importance from both the standpoint of safety and quality. Unqualified propellant can result in uncastable propellant, propellant whose curing rate may result in dangerous exotherms or propellant which would otherwise be hazardous to process during the subsequent operations. During the film you saw some of our acceptance testing. We feel that we know a good deal about the propellant after the acceptance tests are complete and it is with a high degree of confidence that we accept or reject a batch for casting. At present we are qualifying propellant within 40 minutes. With refined techniques now being developed, we hope to not only decrease this time but to improve our knowledge of the propellant characteristics prior to casting.

As previously stated, the process operations subsequent to mixing are believed to be those which must be critically examined

in the processing of large segments, for it is here that we become confronted with very large quantities of propellant. In thinking back over the past ten years of propellant processing, it is interesting to note that there has been a gradual transition to remote control, of many of our processing operations and, in some cases, the discontinuance of certain operations through refinements in process tooling design. The mixing operation, for example, is now completely remote, where at one time certain operations, such as introduction of additives, mixer draw-off, and others were attendant operations. Unfortunately, it has taken major accidents in the industry to bring about some of these changes.

In the casting and subsequent processing of propellant there have been some accidents within the industry, specifically in the curing and end trimming operations. In general, however, these operations remain attendant. At UTC we are studying the casting, curing and finishing operation for large segments very closely to determine the potential hazards and, where necessary, convert to remote operation.

As you noted in the film, we are not presently casting remotely. It is anticipated that in the near future we will be using remotely operated casting valves. Because of the very large masses of propellant we will soon be curing we plan a rather extensive study in determining the exotherms which can occur during this phase of processing. During the curing of our 30,000 pound physical properties vehicle, with a 26" web, there was an indication that an exothermic reaction was present, although exotherms had not been noted during laboratory and scale-up studies of the curing reaction. At the present time we are conducting our curing and cool-down operations remotely.

Although not directly connected with the processing of hazardous material, the handling and storage of cured motors weighing 100,000 pounds and more, must be carefully studied. The handling of 50 tons of anything is a problem, but if that 50 tons is a potentially hazardous material, extreme precautions must be taken in the design and operation of handling equipment. For example, the movement of a large segment from a vertical to horizontal position may seem simple enough, but if the handling fixtures have not been designed properly it can be near impossible to match such things as trunnions to yokes. Or, the matching of segment to segment, which with proper equipment is simple, becomes difficult unless the handling fixtures have been designed with some knowledge of the tolerances and clearances necessary for large and heavy items. We are drawing upon the experience of bridge building, shipyard and powerhouse people to develop the handling techniques and design philosophy for the handling and assembly of large segments.

Storage of the final units is being studied and, for the present, we plan to tie down the units to prevent propulsion of the unit in case of accidental ignition. Immediately after final finishing, lightweight weatherproof closures will be placed over the ends of the segment and will remain in place during transporting and storage until the unit is either static-fired or assembled into a final motor. Thank you.

Mr. Jezek: In the dumping and screening of oxidizer, are the screens and drums bonded? It would appear to me that the polyethylene liner that you use there may cause a problem since the static charge can be built up on this thing. We had an incident at one of our Army facilities which was believed to have been caused by a static discharge from just such a liner.

Mr. Richards: Yes, I would agree with you. I feel that the way we are using these polyethylene bags, there is a chance of static charge. That is one of the reasons why we want to go through different handling systems. During some studies at NOTS we actually poured some propellant out of polyethylene bags and in using a staticator we found that some fairly high charges can be generated. The screens of course are grounded but this is a pretty difficult way to remove static charge. You almost need something like air-ionization or something like that to do a good job. We have seen no real indication of static charge, we have tested around the equipment with things like staticators, etc. and I think most of you appreciate that there is a real problem in measuring static charges although something like this has been with us a long time.

Mr. Levens: In the dumping of the oxidizer drums, I noticed that the personnel were wearing dust respirators. Can you explain the basis for reaching this decision to have them wear these?

Mr. Richards: Why we are using dust respirators?

Mr. Levens: Yes.

Mr. Richards: We have dust.

Mr. Levens: In other words you consider it a nuisance problem. I was interested to know whether you had any problems with dermatitis or irritation of -

Mr. Richards: No, we have actually had no problem. It's simply that dusting does occur and we wear respirators.

Mr. Broom: Can you tell me in planning the layout of your facilities, whether you took advantage of any reduction in quantity in the underground location?

Mr. Richards: Are you speaking specifically of our mixing operations?

Mr. Broom: No, I'm speaking primarily of your casting pit.

Mr. Richards: No, actually we haven't as yet. The casting pit that you saw is all by itself, quite a ways out. We do anticipate putting in another large inground oven which you saw and although I do not know the exact distances involved, it would appear to me at least from the drawings, that we are taking advantage of this what you might call cheap barricading.

Mr. E. R. Holderness, Aerojet-General Corp.: I have two questions. How do you contemplate trimming the end surface of the finished motor and second, from a design and stress standpoint, how do you affect invertion of motors from vertical to horizontal?

Mr. Richards: To answer your first question, we don't end trim. This is done primarily through the design of the charge, process tooling and some refined processing techniques. I presume what you're speaking of is sag. This is now being studied and was one of the main reasons for this physical properties vehicle. This vehicle was the exact diameter of our large segment and there have been calculations made, they don't look bad but this motor has been stored now for about five weeks. Measurements are being made and to be frank with you I don't know the results.

Mr. Holderness: I had specific reference to the tooling and facilities associated with the motor to affect its invertion, not the motor itself.

Mr. Richards: Actually there is a handling harness, sort of this womb-to-womb approach in which we put on this handling harness at the very beginning. We use the travel lift as you saw. There is a fixture that fits onto that and it's a fairly simple operation. It's brought into a vertical position, put down into yokes which match trunions on the handling gear and simply lowered down into the vertical position. The reason I mentioned this is that in some of our early dry fit work we realized we had had no conception of what tolerances were necessary in these handling items, trying to come down with 50 tons in which you've got trunion to try to fit within 1/16" is extremely difficult so what we have done is used a rather simple device like a V shape in which you first match into a fairly large size and then progressively come down into the final yoke size.

Mr. B. H. Minnich, Rocketdyne: You are building quality into your motors, however, after curing one of these completed motors, suppose you find a defect that you would not wish to statically fire this motor, how would you dispose of it?

Mr. Richards: That's a very good question. At the present time, of course, I think we're all quite familiar with the status of non-destructive testing, we are attempting in all ways to find things. We're trying to find voids, we're trying to find separation or other foreign objects. It's extremely difficult to then look at this result and say "no, let's not fire this one, this is not going to be a good one," or "yes, let's go ahead." Our philosophy right now is that we're not extremely worried about things like voids if these voids are not inter-connected. As far as bonds, they have been ultrasonically tested. I would say if we saw something in which there was visual separation, we would attempt to patch this thing up. In the 70,000 pound segments that we fired, there were no indications of such a thing. It kind of reminds me of some of the very early work on Polaris in which a grain cracked and there we were, what do we do with this thing. I think the best suggestion was "let's take it out in the ocean and drop it." In really trying to answer your question, I would say we are going to have to begin to fire some very large units which do have some of these gray areas to help us define what is acceptable and what is not acceptable.

Mr. M. Roy, BuWeps, AZusa, Calif.: One of the talks told us that one of the greatest variables in this whole problem of safety is the human being. I'm kind of curious in hearing the talks about these new plants that have been established as to the considerations that were given to the training and to the problems you might have encountered in hiring new personnel in training them and educating them to the hazards of the jobs that they were doing. Furthermore, these plants are both becoming quite complex and I wonder also if that being the case, if this problem of human engineering and human variability isn't going to become paramount and you're going to be risking a lot of high cost facilities to this variable facet of the human. Was this a problem to you and how have you solved it?

Mr. Richards: It was a problem and the way we solved it, we started actually about two years ago bringing people in who first of all were area supervisors. We took the position that we wanted to try to pound a little technical knowledge into these people. I mean not give them so much that they don't understand it, but at practically all levels of supervision we held a series of seminars which would be repeated every two to three weeks in which we would sit down with these people, go over each individual operation, point out to them the hazards involved and try to get in them some feeling of why we do some of these things. For example, why do we mix under vacuum. It may not be a particularly safety problem, but just why do we do it. It's nice to be able to tell the man. Another interesting philosophy that we have tried at UTC and let's hope it works, is one of trying to build pride into what these

people are doing. This incidentally is not just new to UTC, it's actually a United Aircraft approach which is used very successfully at Pratt & Whitney and this is one of trying to identify the man in the field with his product. It's extremely difficult today for a man who does nothing more than say turn a casting valve, to be able to sit back and say "I really had something to do with that unit." This is the approach we're trying to take, we're trying to teach these people everything we can, we're making ourselves available for all questions and with this background of what we feel are very well informed in the field supervisors, that they in turn can pass this on to their people.

Mr. Roy: Let me add one thing onto it. I assume that this is a continuing operation, this training, and didn't end upon establishment of the new plant. One other comment - in observing your film and the unloading of ammonium perchlorate barrels, I don't know whether your perchlorate is coming in the same condition that the perchlorate that we are buying for the Government (part of the material skipped in recording, editorial changes made by ASESB).. ours have silica gel bags on the top of perchlorate to reduce or at least hold down moisture content and to avoid caking of the ammonium perchlorate. I doubt if your perchlorate has silica gel bags on it unless they removed those prior to unloading. You might check on it.

Mr. Richards: We're using Class 2 ammonium perchlorate with the TCP added and the silica gel bags are removed at the hold room. The lid is actually taken off in the hold room, bags are taken out and it is resealed.

Mr. R. N. Eilerman, Marshall Space Flight Center: (part of material skipped in recording) I have one more question on the oxidizer around the mixer. It appeared in the movie that there was a large quantity of oxidizer on the floor around the charge port. Was this the case or was this just something else I saw in the movie?

Mr. Richards: To be real truthful with you it was calcium chloride since we were taking pictures. This was actually during this film sequence in which we saw the mixer operation itself. Of course, this could not be done with live propellant but was simply done for purposes of the movie.

(part of material skipped in recording)

Unidentified: We have been grinding oxidizer in one of our facilities for about 8 years. We have a fairly good safety record but we have a particle size distribution which is fine enough to get fine dust clouds. You still have enough there particularly with burns and the others to create a problem.

Mr. Richards: I would certainly agree with you and it's rather interesting. I'm not real familiar with publications, but there is a No. 7-230 that is in my mind right now and I noted with interest in reading that, that it mentions that operations of screening, grinding, I believe blending was included, and something like mechanical drying, that personnel should be separated by a minimum of 12" of concrete. This has certainly changed our philosophy and it's something I would like to talk to others about. Again, without dwelling upon this thing, we are not extremely happy with the oxidizer facility. We have a little saying around that we probably have the latest plant but right now it's two years old and we've learned an awful lot. For example, we have installed horizontals and a vertical mixer. I would anticipate that in the future we're going to be buying vertical mixers. You have to remember it is a development facility. It's there for one reason and that is to develop a production type facility from the knowledge that we've learned in this development facility.

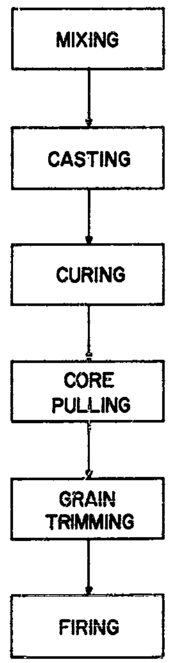
Col. Hamilton: Thank you Mr. Richards. Mr. Lento of American Cyanamid will discuss "Remote Handling of Relatively New Energetic Solid Propellant Materials, Particularly the Preparation of Small Motors used in Static Firing Tests."

Mr. L. Lento, Jr., American Cyanamid Co.: American Cyanamid Co. is one of the "Big Four" ARPA contractors having an integrated R&D contract for Exotic Propellants. This means that we are dealing with highly energetic, unknown compounds, which are usually available in rather small quantities. Therefore, it is desirable to work on a small scale, with all operations as remotely handled as possible.

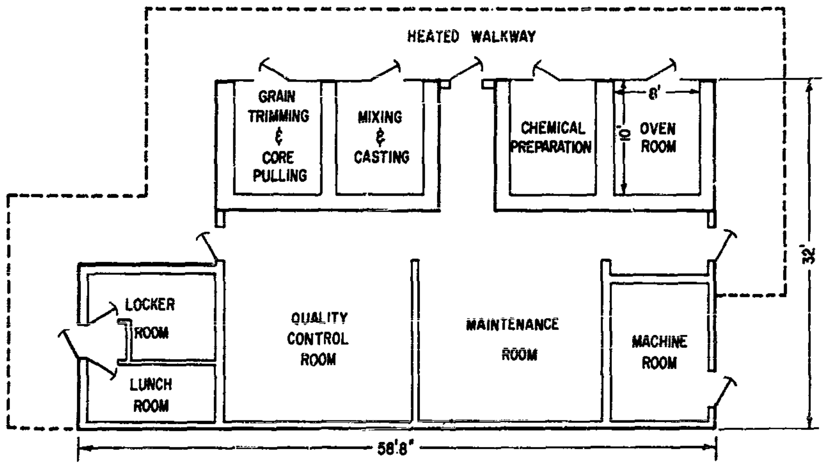
It is in this area, as it applies to motor preparation, that I am confining my remarks today. As you all know, there is a lack of suitable, remotely operated, "off the shelf" equipment available for many of the necessary, small scale operations. I am going to present another approach to these problems that I believe is somewhat different from the remotely operated, mechanical arm techniques, that have been presented from time to time.

Before I do, I would like to show you a line drawing of the motor preparations flow chart shown on the first slide. There is nothing new here, but this chart does show the operations I am going to discuss. The next slide, shows our arrangement of the conventional cubicles for hazardous operations, and the safe areas used for laboratories and hardware preparation.

MOTOR PREPARATION FLOW CHART



Slide 1



SOLID FUEL PREPARATION BUILDING

Slide 2

Some of the features of this building are:

1. Anti-spalling plate in front of the 18" of doubly reinforced concrete for personnel protection.

2. No viewing windows in the front wall; we are completely dependent upon closed circuit television for all operations.

3. Burn out, blow out walls and ceiling in the four cubicles.

4. Reinforced concrete ceiling over the safe area, and last but most important is

5. Heated Operational Walkway.

American Cyanamid's test facility is located in Hingham, Mass. on Boston's South Shore. Due to its location, we have a problem that our more fortunate brothers do not. We have snow! Last winter we had plenty, and the spark proof, conductive walkway was free, clear, and dry even in the blizzards.

Before leaving this slide, I would like to point out that the cubicles are air conditioned for 70° F. and high humidity (50% R.H.), to eliminate static build-up.

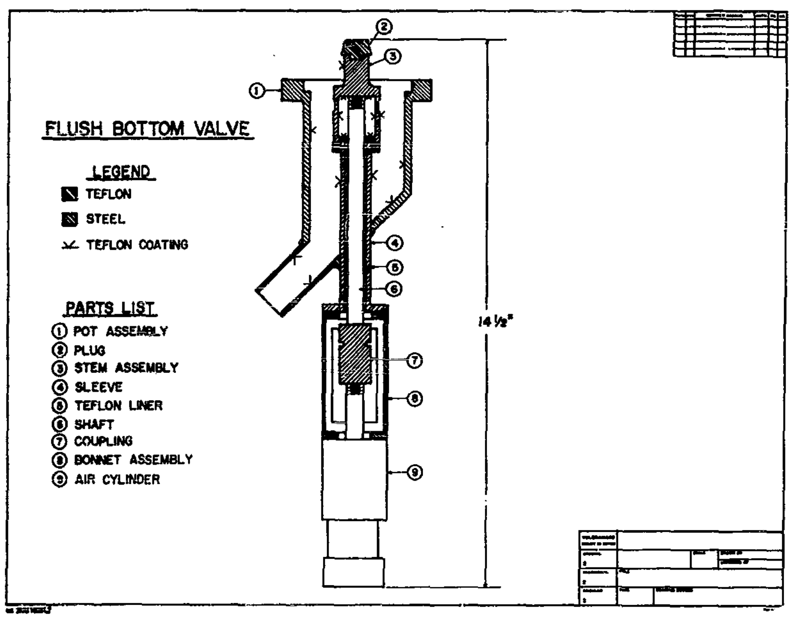
I would now like to talk about the air operated flush bottom valve that we have designed. The next slide shows a picture of the valve. Note that the valve has an overall length of only 14", which is considerably smaller than anything available on the market today. The next slide shows a section of the valve. You will note that all of the surfaces in contact with the propellant and moving steel parts are Teflon coated. Also note the replacable Teflon plug, and the O ring seal. This valve has been designed so that it is impossible to have metal to metal contact, and it is impossible to have propellant enter the stem assembly.

We have prepared a motion picture to show you the following:

First, a view of the anti-spalling plate wall from the laboratory side, with the pneumatic, electronic, electrical, water and steam remote controls.

Secondly, you will see the remote ingredient addition to the Baker-Perkins double planetary, vertical mixer. You will see the casting of the propellant into screening motors and the remote positioning of the motors under the feed tube.

Slide 3



Slide 4

Slide 5

Thirdly, you will see the remote Core Extractor, pull the mandrel, separate the cap from the motor body, and finally separate the motor body from the casting base.

Lastly, you will see the Grain Trimmer remotely trim the grain from one end of the motor then index the motor so that the other end can be trimmed.

I would like to point out that all of the equipment you will see in action has been designed by our engineering staff.

The modified drill press that you have just seen has a great deal of flexibility. We use the Grain Trimmer to drill holes in strands, by simply placing the pin vise in the Jacobs chuck, setting the limit switches, alinging the drill point with the hole in jig, and push the start buttons. The Grain Trimmer is also used to cut strands from a sheet of propellant by the use of a multi-guillotine bladed plate. The jigs are shown on the next slide (5). The blades are pushed down through the propellant sheet by a plate that has been previously mounted in the Jacobs chuck. In this instance only the advance mechanism of the Grain Trimmer is used. In a similar manner "dog bones" for tensile testing can also be cut remotely.

Now that you have seen the Trimmer in action, I am sure that you will agree that it is a very flexible, useful device.

Mr. Holderness: I'm interested in that grain trimmer in that 'does the knife cut the propellant right up next to the motor case'?

Mr. Lento: Yes it does. You remember on the first slide that we showed, all that was in there was a little bit of flash. I recognize you're back so far you couldn't see it. It does cut right off next to the wall. I want to add too that we've designed our filling casting equipment so that the cap and the base are square edged and so that they actually give us a little groove, a little extra advantage so that we hope it will give us some room between the end of the propellant and the wall itself, but it does trim right up to the wall.

Mr. Holderness: The reason for the question was, in contemplation of trimming operations on a full scale motor, our safety office and engineering have considered it unsafe to let any metal cutting tool come within any reasonable proximity to a wall. I'm wondering what safety precautions or engineering went into the construction of the tool that allows you to come so close to the wall.

Mr. Lento: There are very definite dimensions, or I should say distances, out from the center for each of these three blades and so there is room for them to move back and forth within the concentricity of the motor tube and then by use of this long shaft which again is a flexible shaft, we are then able to get very close to the wall. We're dependent entirely upon a piece of stainless steel in contact with a piece of brass. We hope this will not give us any problems.

Mr. T. F. Morrissey, Aeronutronic: I was interested in the floor plan you showed of the propellant handling building. Could you tell me what quantity you designed this building for?

Mr. Lento: Yes, this building is designed for 15 pounds of high explosives 1' from the wall. I don't know the formula that our construction people used, but certainly it's an accepted one. I saw the building go up. It has 1¼" reinforcing rods, 9" on center with cross bracing of the same diameter and this is true, no matter which way you would cut this wall. In other words, whether you would cut it like so or like so or like so, no matter how you cut this, you would still have this same configuration. I would hate to have to take those walls down myself at least without some energy.

Col. Hamilton: Thank you very much Mr. Lento. The next item "Problems in the Handling of Small Quantities of Propellants in Research Operations" will be presented by Mr. Thomas F. Morrissey who is the Safety Director for Aeronutronic, a Division of the Ford Motor Co.

Mr. Morrissey: Several months ago, when asked to suggest appropriate subjects for discussion at this seminar, I replied that an item of interest to me was the problems encountered in the application of existing regulations to the small and varied types of operation of a research and development organization. This type of problem absorbs a good deal of my time each day and, in doing research for preparing this talk, I found that other groups find themselves in somewhat the same situation.

My employer, Aeronutronic Division, Ford Motor Co., like most other private research and development industry, does not direct its efforts primarily toward the propulsion field. Although we do a fair amount of original and developmental work in both the liquid and solid propellant fields, our facilities are not constructed solely for this purpose. I think that most Aerospace organizations have found that many of their projects, especially those relating to space vehicles, include small amounts of ordnance items such as explosive bolts, small thrust rockets, shaped charges, and squibs.

Items of this nature are handled by many groups within the Aerospace Industry, and, in many different areas of facilities, sometimes without regard to regulations governing their storage, handling, and transportation.

There are a number of reasons for this. In some cases, it may be that there is an unawareness of applicable requirements; but probably, if the requirements were known to everyone, a good portion of the affected groups would not be able to comply without major structural alteration of the premises.

It appears that there are three general approaches to compliance with safety regulations set forth by the military, civil, and other authorities having jurisdiction over explosives operations. They are:

1. Ignore all regulations. This approach is usually found among the small companies who may be sub-contracting work and whose operations seem to be by-passed by the several inspection agencies. This type of operation many times eliminates itself, as these companies usually fail because of poor management, liability lawsuits, or their luck just runs out.

2. Adoption or modification of the regulations of one authority in preference to those of other authorities. By this method highly restrictive rules are circumvented and conflicting regulations are avoided. This approach is found most often within moderate size companies who wish to operate safely, but do not want to tolerate costs and inconvenience that accompany complete compliance.

Some perils also accompany this type of operation. Difficulties with inspections are sure to arise and the possibility of incurrence of liability is always in the background.

3. The final method of dealing with safety regulations is that which is usually taken by large organizations and those who are subject to frequent scrutiny by inspection groups. This involves a direct effort to comply with all regulations, choosing the most restrictive parts of the rules promulgated by all authorities. This philosophy is desired for several reasons:

- (a) Ultimate in safety
- (b) Vulnerability to lawsuit
- (c) Preservation of reputation
- (d) Harmonious relations with authorities
- (e) Ability to afford compliance.

At present Aeronutronic makes every possible effort to fall into the group that is complying with all of the regulations. By doing this we find ourselves sharing a problem common to many Aerospace companies.

The difficulties involved in the adoption of this philosophy are twofold:

1. The technical problems in the safe handling of propellants;

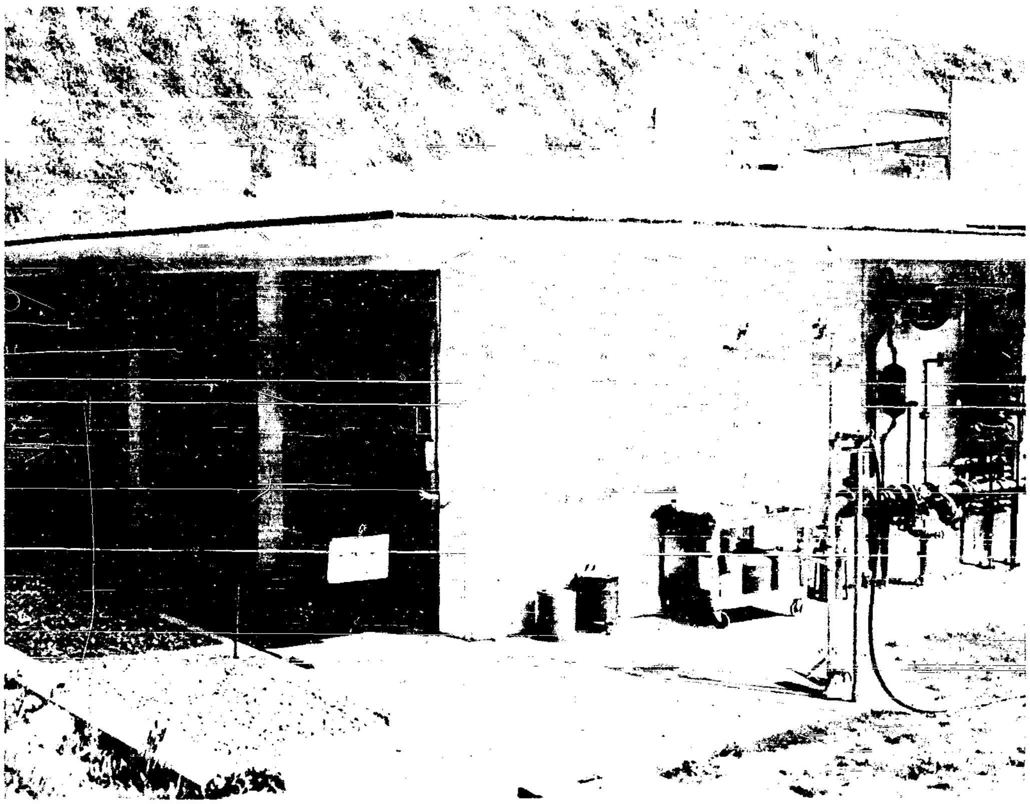
2. The administrative problems of adhering to regulations.

Many times the second of these is the more troublesome. The greatest difficulty that is met in handling small quantities of ordnance items is complying with quantity-distance limits. A look in the Ordnance Manual M7-224 indicates that to handle Class 9 materials you must be 300 feet from other operations if the net amount of explosives is between 0 and 50 pounds. This distance may be reduced one-half if proper barricades are present. Unfortunately, there is no breakdown smaller than 0 to 50 pounds. Therefore, to handle less than one-pound quantities of a Class 9 material, legally, one must be in an isolated area.

This rules out the handling of shaped charges, small thrust units, and other Class 9 items in existing environmental, physics, chemistry, electronics, and other laboratories; assembly and check-out rooms; and similar operating rooms. I am sure that a hazard potential exists and that the quantity-distance requirements may be realistic when you are approaching the upper end of the range being used here as an example, but that the hazard does not warrant such restriction on very small items.

In the handling of Class 2 materials, which includes most of the composite propellants, the situation is a little vague. There are no quantity-distance requirements published and interpretation must be applied. Unfortunately, different people have supplied different interpretations to me. Also, the State of California does not distinguish classes of propellants. Rather than discuss the application of M7-224 to small quantities of propellants in research operations, I would like to point out that this manual was developed originally for conventional explosives and go on to a suggested modification of its principles for propellant usage. It is obvious from recent revisions that the people responsible for this manual are already moving toward this goal.

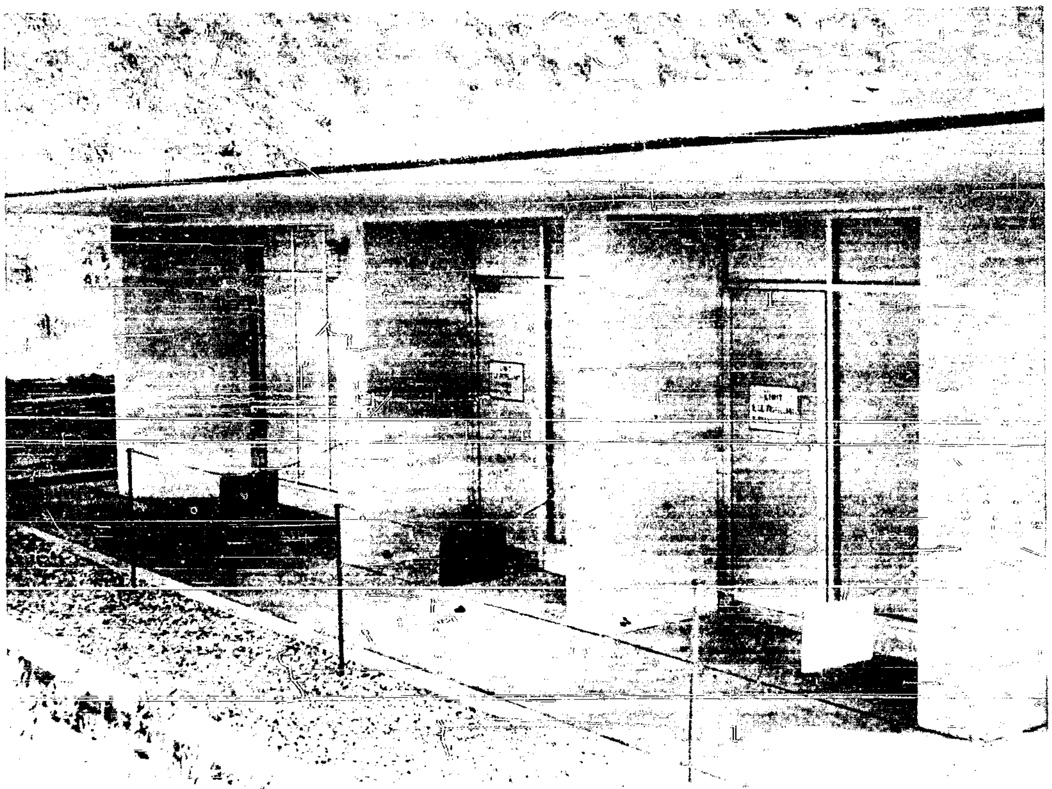
Safety in propellant operations is usually approached by the individual or concurrent use of isolation and operating shields. Thus, we have quantity-distance tables and specifications for operating shields and barricades.



Here is an example of the use of isolation and substantial dividing walls. (Slide #1 - Solid Propellant Laboratory) Facilities such as this cost about 100 dollars per square foot, exclusive of operating equipment. Note the fire protection system piping.

Slide 1

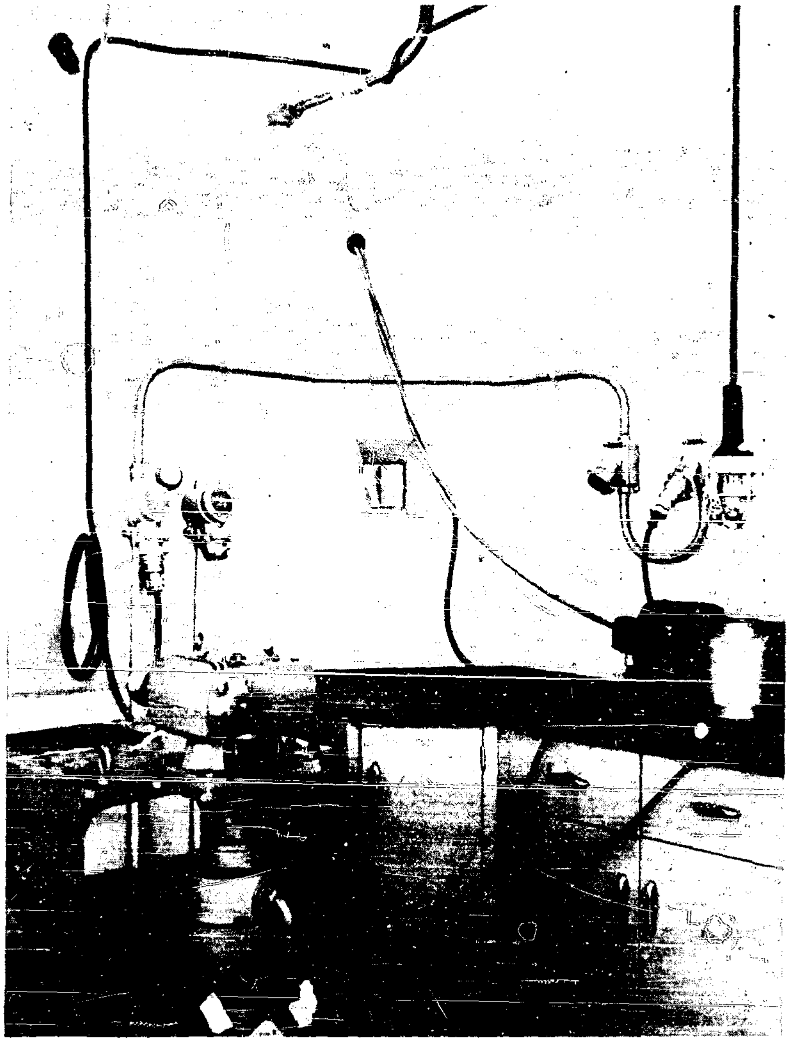
UNCLASSIFIED



A second view gives a better indication of the thickness of the walls and the blow-out paneling.

Slide 2

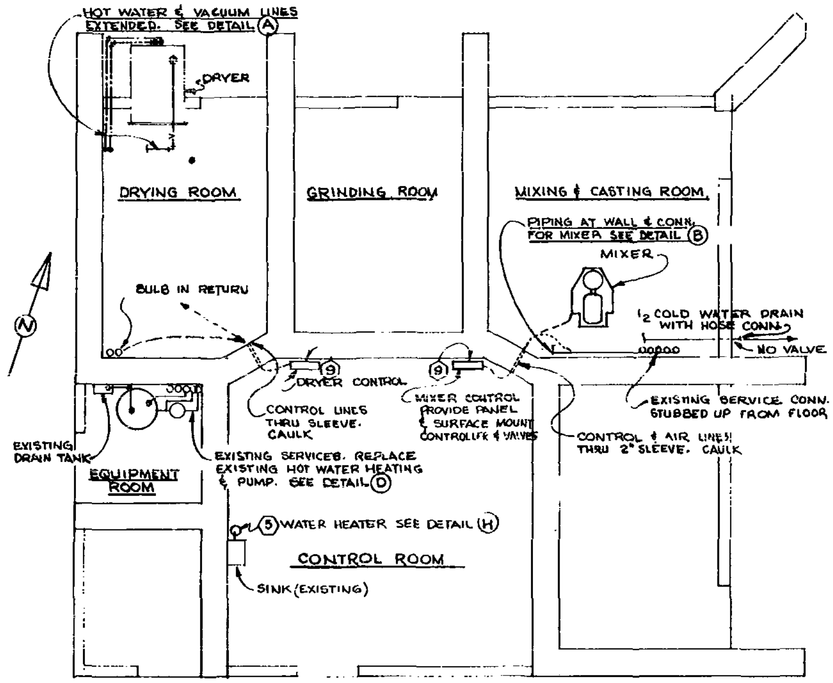
UNCLASSIFIED



This interior view of one cell shows more details of construction and control lines for remote operation. A 1 lb. mixer is set up and a 10 lb. mixer can be seen that is uninstalled because of quantity-distance deficiencies. Note the deluge head in the upper left hand corner.

Slide 3

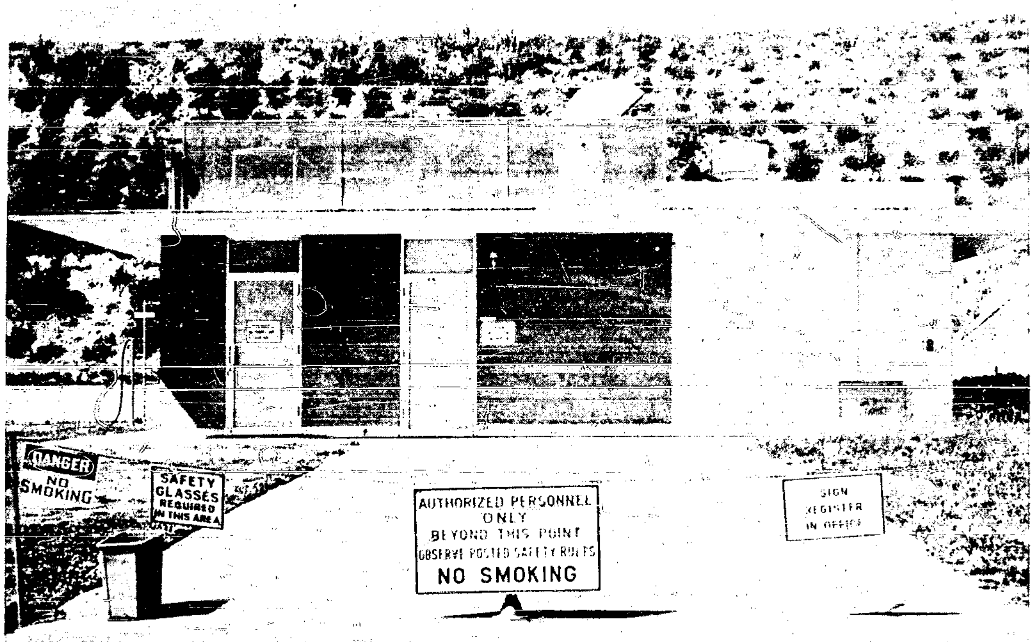
UNCLASSIFIED



PLAN – SOLID PROPELLANT LAB
SCALE 1/4" = 1'-0"

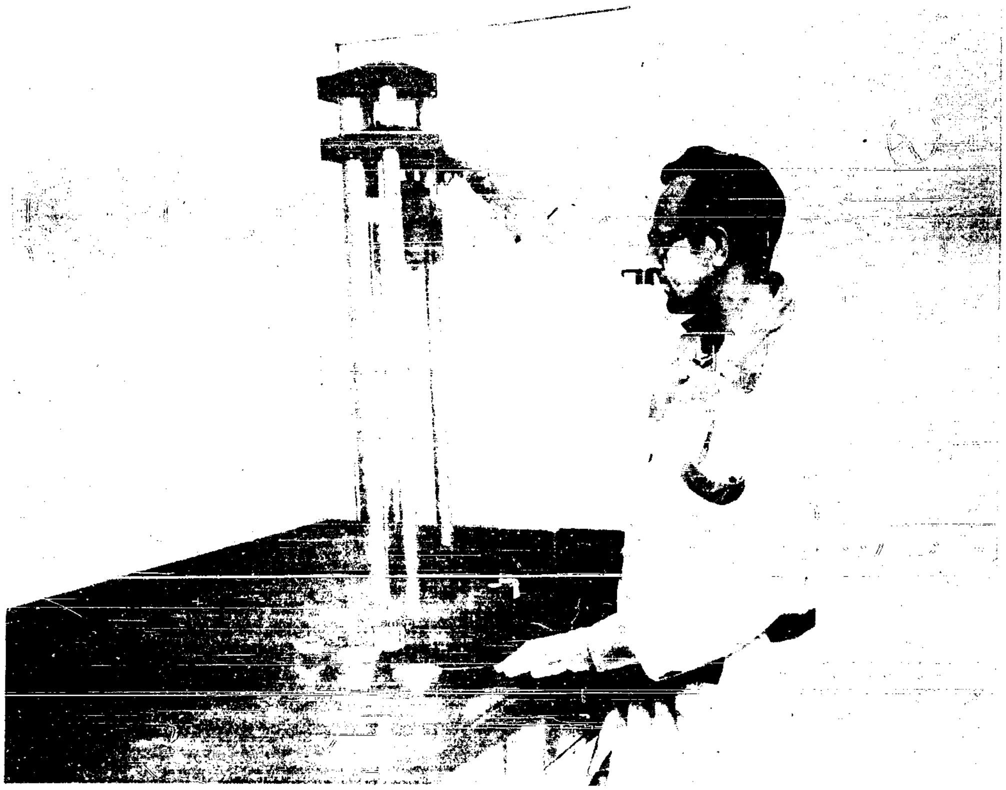
Slide 3b

UNCLASSIFIED



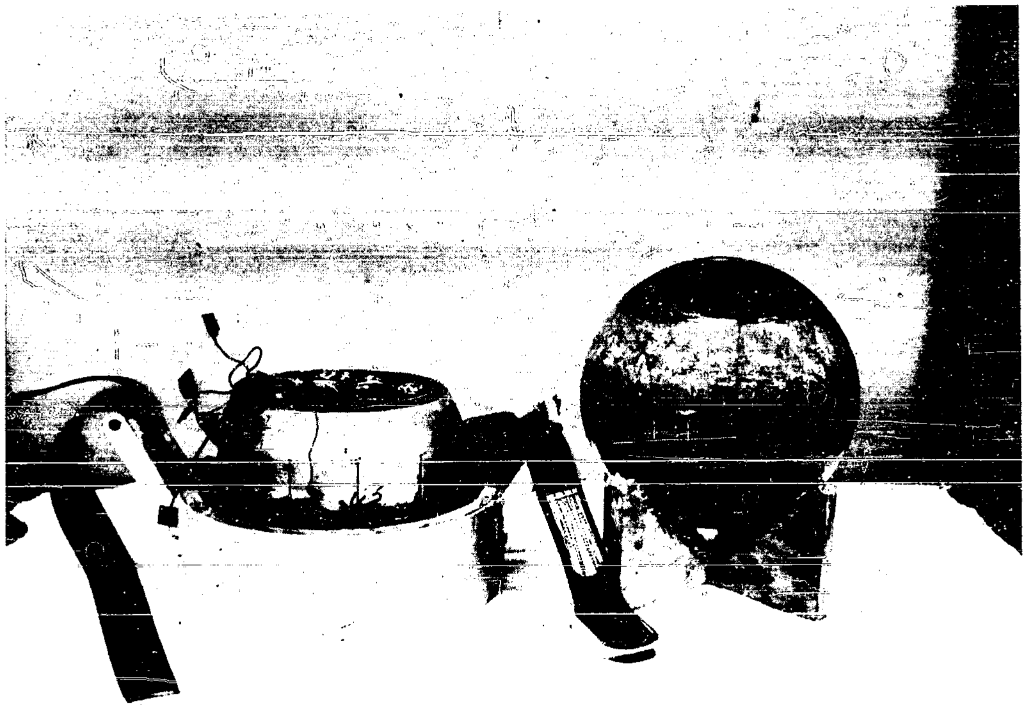
This view of the laboratory shows an excellent example of a natural earth barricade on the operating side.

Slide 4



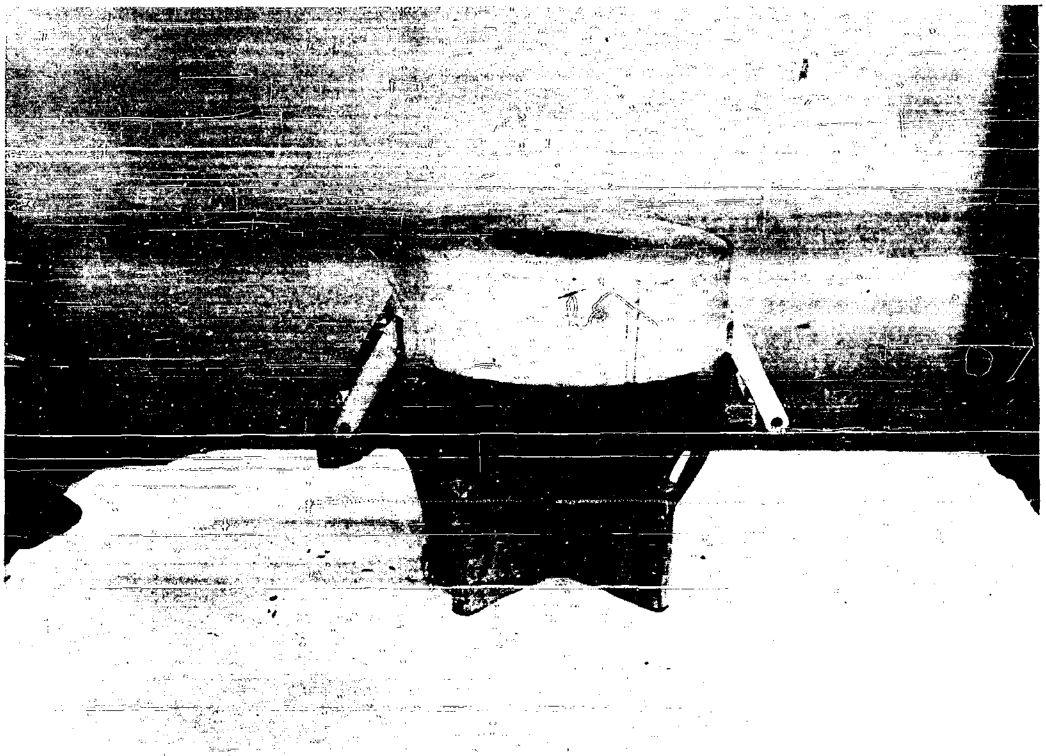
Another method of shielding (Slide #5) can be seen in this man's use of a plexiglass shield when using smaller laboratory equipment. He is also using personal hand and eye protection.

Slide 5



Safety in use of laboratory quantities can be achieved by shielding without isolation. In Slide #6 we see an inert and a partially completed section of a Lunar Capsule. Lethal projectiles can be and have been accidentally actuated and expelled from this device.

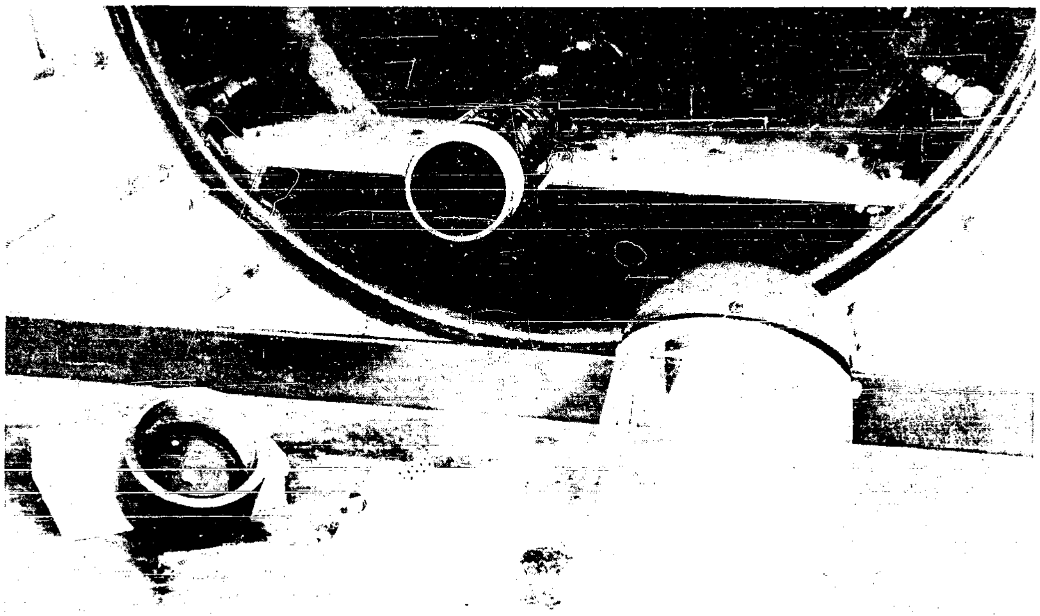
Slide 6



The use of this shield (Slide #7) gives complete protection against such mishap as effectively as isolation. This shield was installed from the first build-up of the capsule and has saved an employee from serious injury or possible death.

Slide 7

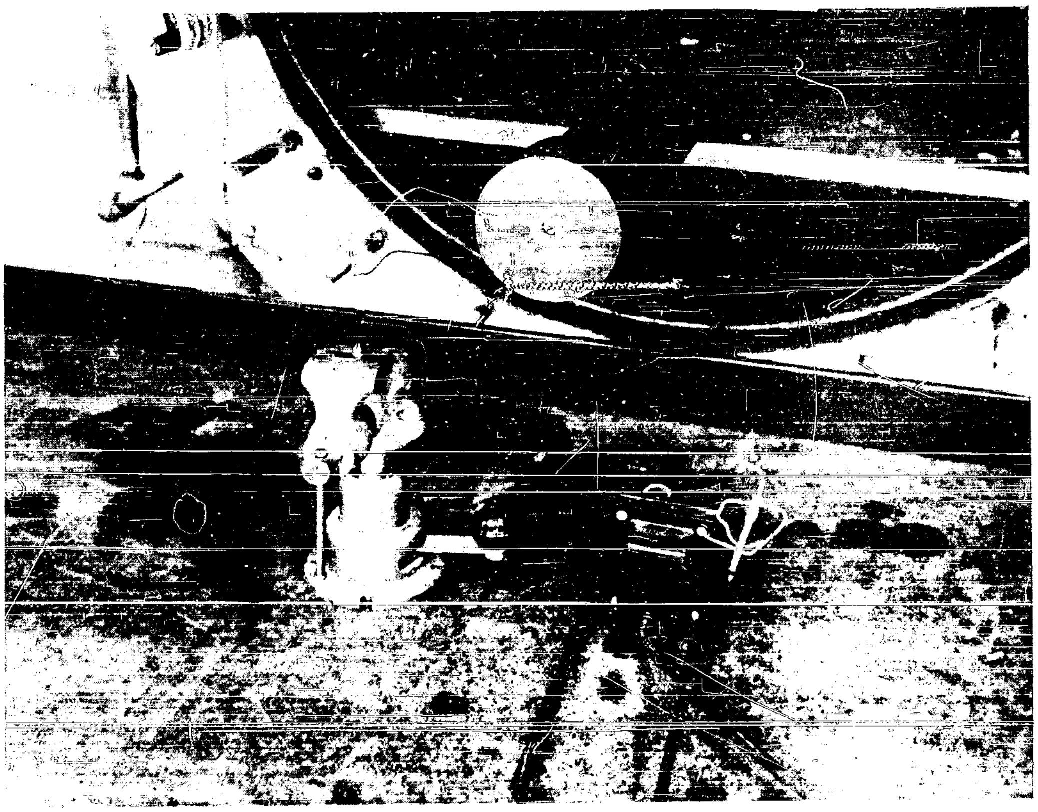
UNCLASSIFIED



Here we see a method of completely protecting an igniter assembly operation.

Slide 8

UNCLASSIFIED



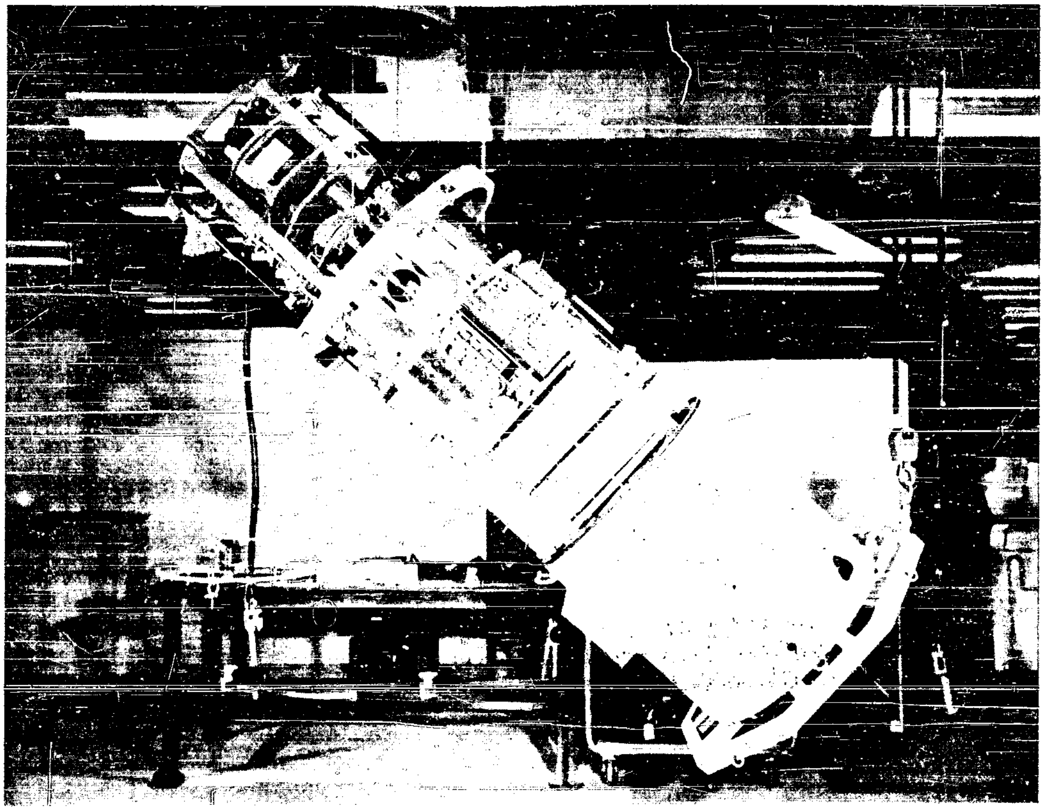
The igniter can be screwed into the small tapped hole of the pipe cap and when the cap is in place a soldering operation can be carried out without any hazard to the operator or other personnel if present.

Slide 9

"POOR DEVIL..... HAS FIVE DAUGHTERS AND ONLY ONE BATHROOM AT HOME."

Safety Shower

Slide 10



Slide #11 is a view of the payload carrier for the "Blue Scout" missile. It contains several pounds of explosives divided among many small items, most of which are of relatively low hazard class. One of these is a small Class 9 item. One authority offered the opinion that "by the book" all of the materials should be considered in the classification of this higher hazard item during assembly. Our analysis of hazard indicates that the maximum mishap would not be of consequence outside of the immediate assembly area. Thus, Class 9 quantity-distance requirements are not warranted. The best protection here is personnel training and good operating procedures.

From these few examples, it can be seen that the problem in many research and development operations is to protect immediate personnel and that there is virtually no hazard to other facilities and the surrounding area. Thus, the relaxation of some of the existing safety requirements would allow more expeditious and economical handling of ordnance items associated with the defense effort. Caution must be used in this approach so as not to dispense with safety; but in the period we are now entering I would not want the safety people to be accused of "gold plating."

Another perplexing aspect of research and development involving propellants is the transportation of explosives. Until recently, newly developed items could only be shipped in very small quantities as laboratory samples for examination until ICC classification was obtained. In our rapidly changing technology, a propellant can become obsolete before it can be transported. The solution to this problem is already at hand. For the last several months the Air Force has had authority to classify propellants for the ICC. Our experience has been that this service is very quick, and most helpful.

When transporting explosives by private truck, other problems arise. In the State of California, there are four authorities to be dealt with. These are: 1) Health and Safety Code; 2) Vehicle Code; 3) the ICC; and 4) the California Administrative Code. Each of these applies under different circumstances, but you are always subject to one or more of them.

Recent revisions of the Health and Safety Code and the Vehicle Code bring them into close agreement as to responsibilities, but you must be familiar with each to determine under which of these each individual explosives transportation operation is to be carried out. Their definitions of explosives are identical and reasonable. Many propellants are excluded from regulation.

On the other hand, the California Administrative Code contains a section on transportation of explosives. Under "Definitions" the following statement appears:

"4111 (c) Explosive, as used in this article, includes any of the following: (1) ....
(2) A substance to be exploded or ignited to produce a force for propelling missiles or rending other substances.

4114 (a) Any vehicle transporting explosives shall display upon each side and the rear of the exterior of such vehicle a sign upon which shall appear the word "Explosives"

in letters not less than three inches in height upon a background of sharply contrasting color. (There are no quantity exceptions)

(b) Detonators and capped fuses should not be transported in the same vehicle with other explosives. If they are carried in the same vehicle, the detonators and capped fuses shall be in a separate compartment from the other explosives with at least twenty-five inches of air space between the two compartments."

These regulations place severe restrictions on the transportation of all propellants even in minute quantities. In addition, they prohibit the transportation of some of the newly developed propellant systems with integral detonators.

I am very happy to be able to conclude this presentation without the offering to the military of a list of recommendations for their action to help the research and development organizations with their problems. This is unnecessary since I discovered just last week that the Armed Forces are not unaware of the problems of their contractors and are endeavoring to be helpful when the situation warrants their taking action. The Munitions Safety Requirements Branch of the 2705th Airmunitions Wing of Hill AFB, Utah, is now developing explosives safety requirements for laboratory operations. I understand that this new technical order will allow considerable latitude in the handling of propellants in laboratory operations and will be based mainly on the use of "sound judgment and prudence." Quantity-distance requirements will be liberalized and some of the rules to be followed will be:

(1) Limitation of quantities on hand to a one-half days' supply.

(2) Restriction to handling of materials in the quantity of about five pounds.

(3) Separation of wet from dry operations.

(4) Segregation of operations involving liquid and solid propellants.

(5) Use of standard operating procedures.

(6) Reliance on safety devices, shielding and protective equipment.

(7) Well thought-out personnel limits.

(8) Careful control of toxicity.

It is gratifying to know that there is constant evaluation of the problems of handling propellants and that regulations are being modified to provide reasonable safety without undue restraint. I appreciate the opportunity to point out safety problems in the research and development of propellants and to advise others that where solutions to safety problems exist, the military authorities having jurisdiction are willing to act. Where difficulties exist, with local regulations, I can only suggest that we donnot sit back and allow problems to compound, but make an active effort to obtain regulations based on acceptable risk factors and reasonable cost. It is these two items that should govern all safety regulations.

Col. Hamilton: Thank you very much Mr. Morrissey. Any comments or questions?

Mr. Bishoff: Do you have a contract with Army Ordnance?

Mr. Morrissey: Yes, we do.

Mr. Bishoff: In the Los Angeles District?

Mr. Morrissey: Yes, we do.

Mr. Bishoff: I would like to refer to your problem on explosives safety distance requirements for quantities up to 50 pounds. The Army Ordnance Corps will accept the ATD in these quantities based upon a review of your facilities and explosives limits that you're willing to set up. My suggestion to you is that you contact Mr. Burton H. Cousens at the L. A. Ordnance District and he'll arrange to get the necessary correspondence then to OCO.

Mr. Morrissey: I'll check with you later. We have been in constant contact with Mr. Cousens.

Mr. Bishoff: On your remarks regarding tables for propellants, are you aware of the Ordnance Manual 7-230?

Mr. Morrissey: This is a rather recent one?

Mr. Bishoff: It's approximately a year old.

Mr. Morrissey: Yes, I have a copy.

Mr. Endsley: I don't have any quarrel with you, you were most complimentary to the Air Force on their progress in getting these tables and things out. However, the one thing that does worry me

somewhat is the local state regulations that might be binding and I understand we have a member of the Transportation Conference I believe is the title. If he is in the audience, he might be able to give us some light on some procedures or streamlining the procedures to get the state legislation changed where we might have more flexible commodity movement. He may have checked out.

Mr. Morrissey: We have two staff attornies right now working on trying to determine what applies and what doesn't apply in the State of California to transporting explosives and it appears that the main stumbling block is the California Administrative Code. The other authorities have all gotten together and evidently sat down with the ICC because they refer almost all of their regulations to the ICC and even state that nothing in their rules shall be construed to be more restrictive than ICC regulations which is a very fine approach but then you come to the fourth agency and our contacts with them indicate that they went through all the regulations existing by various authorities, the NFPA or any other authority they could find who writes safety regulations and they picked out the most restrictive point in them so that they could publish the safest regulations.

Mr. R. E. Benshoof, Marquardt Corp.: Our problems are very similar. I might just merely point this out. I'm not so worried about the state requirements, I think you have to start at the bottom and work up in this field for the simple reason that it is very difficult to go through the City of Los Angeles. The City of Los Angeles Dangerous Chemical Code insofar as the transportation of hazardous materials is concerned is the most restrictive in the United States and I would respectfully suggest that you take a good look at that and get clearance from them. Because if you get clearance from them, you should be able to get by the State with no sweat.

Mr. R. E. Hart, Bureau of Explosives, AAR: The Vehicle Department Highway Vehicle Code - they are aware of the confliction between ICC regulations and their own regulations with regard to placarding. This was brought to their attention a couple of years ago and at that time there was a rumble of changing the vehicle code. This hasn't been done to date but I know that they're very well aware of it, and it does add many conflictions.

Col. Hamilton: Thank you very much Mr. Morrissey. The next two items on the agenda have been combined. The authors of the paper are Dr. Karl F. Ockert, Dr. Robert Petry and Mr. Kenyon Stevenson, all with the Rohm & Haas Co. Dr. Ockert will make the presentation which is entitled "Personnel Shielding in the Handling of Small Quantities of Ingredients for High Energy Solid Propellants."

Dr. Ockert: The problem of protecting personnel from explosives hazards is one which all of us in the rocket business face. Until recently, attention has been focused almost exclusively on materials in bulk quantities, viz., large motors, mixers, etc. With the interest in high energy solid propellants and in associated synthetic programs sponsored by the Advanced Research Projects Agency (by whom this work is also funded), we are forced to institute protective measures continually earlier in the research and development sequence. Certain new areas in chemistry are fruitful lines of research leading to high energy compounds suitable for both liquid and solid propellants; however, as many of us can testify to our sorrow, these substances are extremely temperamental. The situation is made even more awkward by the fact that in order to synthesize enough material for large scale tests, such as the card gap test, we may have already found out the hard way what we want to know.

We at Rohm & Haas have taken the position that certain classes of new substances may detonate at any point in synthesis and scale-up and, indeed, are likely to. As a long-established organization on an Army facility, we cannot make drastic modifications of our facilities by extensive use of robots, or by increasing quantity distances or by erecting additional heavy barriers; we must adapt what we already have. In this paper we shall cite some examples of measures we have designed, checked and adopted for safe manipulation of explosive materials in quantities from a few grams up to a pound[1].

Bench-Top Containers and Shields

First, consider the problem of protecting technicians in an open laboratory in which it is necessary to maintain, at least for a short time, small batches of potentially detonable materials. Such substances must be confined and confined in containers reasonably small in size and light in weight.

Following a suggestion of duPont, we tried vessels with polyurethane confinement. Glass vials were embedded in solid, rubbery polyurethane, which had formed in molds made of large polyethylene bottles. A ½" diameter vial in 7/8" thick polyurethane successfully confined products of a No. 8 electric detonator but disintegrated with 3 grams of C-4 plus detonator. With a somewhat larger vessel,

[1]This Division's work on gloves, goggles and lightweight shields for very small quantities was published some time ago and was recently (February 1961) reprinted in an expanded form as Rohm & Haas Rpt. No. S-28 (unclassified). Our tests of various wall structures for confining multi-pound batches have been discussed before this very group two years ago at the Naval Propellant Plant.

1" in diameter and having a larger "web," 1" thick, 2.2 grams of C-4 plus a No. 6 detonator was successfully confined, although a hole was blown in the base of one container because the thickness of the plastic was only 9/16" at the bottom; 3.1 grams of C-4 plus detonator shattered the container walls. The particular containers tested had glass liners. Consequently the debris was blown out the top; moreover these holders were, to some degree, propulsive. Therefore, safety goggles and other auxiliary equipment still have to be worn by personnel using such containers, even within the safe limits of 2 grams. For many applications, it is not necessary to use a glass vial. For use with liquids, for example, the large mouth of the vessel can be eliminated by using a 1" diameter glass sphere imbedded in 1" thick web polyurethane with two small stopperable glass stems leading through the plastic. Eastern Laboratories of duPont have made extensive studies of these polyurethane containers in a wide variety of sizes.

For larger quantities of explosive, the polyurethane container becomes somewhat cumbersome, owing to its size, and we have searched for other means of confining the primary debris and direct blast effects. Our next approach has been to use various sizes of ordinary water pipe, open at both ends. Schedule 40 steel water pipe in 4" diameter and open at both ends is burst open by a 25-gram charge of C-4. Five inch water pipe, 10" long, successfully withstands the blast from a centrally located C-4 charge of as much as 75 grams. If we use solid polyurethane inside 5" pipe to hold the sample, a 40-gram charge gives extensive deformation of the container and chunks of polyurethane are blown out of the container and about the room. Use of the polyurethane foam, however, gives the same result as if we were using air, without the disadvantage of debris which a heavier filler creates.

The open pipe type container is quite useful for multigram quantities of explosives; however, in order to avoid being subjected to the direct blast at the vented ends of the pipe, two persons at a distance of 2' away are required to move such a shield. In addition, supplementary protection from the noise would be required.

Experiments with complete confinement indicate that 25 grams of explosive can be adequately confined in a container much smaller than an open pipe. Taking a cue from Esso Research's work, as reported at the 17th JANAF Solid Propellant Group meeting at Denver in May, we tried some 2.2" I.D. x 3.4" and 3.2" I.D. x 4.3" heavy wall pipe (Ladish) of ASTM A-105 grade 2 steel, plugged at both ends. Although the threads were NPT and the lid was put in only finger tight, the smaller container (0.41" wall thickness)

successfully held 7 grams of C-4 explosive. The larger container (0.6" wall) held 20 grams; at 25 grams the plug was ejected. In no case was there deformation of the container or the lid apart from the stripping of the threads.

More recently we have tested vessels machined from 4130 and cold-rolled steel bar stock with 3 and 4¼" outside diameters and 3/8 and ½" thick walls, respectively, and with untapered threads. The smaller containers successfully confined 15 grams of C-4 plus detonator, although the container was so deformed that the lid could not be removed. The larger container confined 25 grams of C-4 with some deformation. Where the lids remained in place, the vessels, despite a small vent hold for accepting the lead of the detonator, were not propulsive. Further design experiments are in progress.

Shields for Synthesis of Multigram Quantities of Explosive Compounds

So far, we have dealt with vessels to confine detonation of materials in static condition in the laboratory. A quite different problem arises when we consider protecting personnel during the handling of these chemicals in the course of synthesis and purification. For the performance of laboratory scale synthetic processes we have erected a series of three boiler plate shields in an expendable structure mounted on a concrete slab with a Transite roof and sheet polyethylene and lathe walls. Each shield is open on one side and the second two shields have windows, opposite the open sides, made of two 2" thick Plexiglas sheets. In the first shield the synthesis itself is conducted in a batch process. The crude product is collected in a trap and is transferred through an armored line to a second shield, which is the weighing station. The weighed fraction is transferred, again through a shielded line, to the third shield for purification by distillation.

The two windowed shields have been tested with 100 grams of explosive while furnished with hardware to be used in practice. The smaller of these (the weighing station) was 2' x 2' x 3', fabricated from continuous welded 3/8" boiler plate. Apart from loosening of the anchors and slight bulging of the walls, the smaller inclosure successfully withstood the blast effects of 100 grams of C-4. Damage to the building was exactly what it had been designed for - the roof was raised approximately 1" and panels of polyurethane sheeting were either blown free by the blast or billowed inward by the rarefaction wave. The operator would have been protected from debris but might have been buffeted about by the secondary reactions. Since the 3/8" anchor bolts set into the concrete floor were pulled loose about an inch, the weighing station shield was bolted on 8" heavy gage beams set in 18" of concrete.

The shield for the purification step was 80" x 60" x 30" x 3/8". Because the distillation process requires a Glascol mantle or an oil bath, we first detonated 100 grams of C-4 immersed in water in a 1 quart aluminum saucepan. There was no blast damage to the building except for rupture of the polyethylene sheet facing the exposed side of the shield and a half dozen 1" holes knocked in the transite roof by direct hits. A second shot, in air, gave evidence of somewhat greater blast, but even this was relatively mild. Only a couple of polyethylene panels on the operator side were torn; none of the doors was blown open nor were light objects displaced by either blast or rarefaction waves. These steel shields should provide more than adequate protection for operating personnel during the synthesis and purification of potential explosives in quantities as great as 50 grams.

Protection from Pound Quantities of Confined Explosives

Up to this point we have dealt with potential explosives in what we choose to call laboratory quantities. Scaled up synthesis requires more rugged equipment than glass. This introduces the additional hazard of shrapnel from metal reactors, condensers, and tubes. At Redstone, we cannot maintain large distances between the operator and the reactor; we are limited in at least two locations to a maximum standoff of 12" from a 3/8" boiler plate partition. In order to find the extent of damage which would be sustained by this wall in the event of a high-order detonation in the reactor, field tests were conducted with ¼" boiler plate and one and two pound C-4 charges in various confinements. One eighth inch wall copper tubing confining a one pound C-4 charge punched holes in two ¼" steel plates at a distance of 3 ft. Even 1/32nd inch wall type 304 stainless steel with one pound of C-4 perforated a single plate at 12 inches (the greatest distance attempted).

Bearing in mind the effectiveness of separated concrete walls in confining missiles from detonations of large quantities of explosives, we investigated the usefulness of a sacrificial intermediate barrier. The damage sustained by witness plates with the addition of an intermediate barrier was much less in degree and quite different in character. Without such a barrier, 2 lbs. of C-4 confined in 2" or 4" water pipe perforated a single ¼" plate 14 feet away. With an intermediate barrier of 12" water pipe around the charge, a single plate 12" away sustained only scars and slight deformation. The intermediate barrier itself was destroyed but gave only large, low-velocity fragments. There was no evidence that shrapnel from the primary charge confinement reached the test plate. 12" diameter pipe shields were immediately installed about critical locations in our chemical processing facilities and have already demonstrated their worth.

There remained yet another problem aggravated by our cramped quarters, namely, blast effects on the boiler plate walls. A slow explosion, in which, fortunately, there were no injuries, of a mere 60 grams of flammable material in air, with whatever oil fumes also existed in the cell, demonstrated most vividly the inadequacy of simple ram-setting of the partition into the concrete floor. Also, mounting of the steel doors proved to be unsatisfactory. After field-proving the utility of supporting the partitions by compressive members (in our case, 1 3/4" angle iron, 1/4" thick) the partitions were all remounted; in addition, doors were reinforced by welding on angle-iron X's and hasps were replaced by 1" x 2" x 8" dogs on 7/8" bolts.

Attempts to apply the principle of sacrificial barriers to containers for manual transportation of a pound of high explosive were unsuccessful. Combinations of water pipe mounted concentrically in pairs by means of polyurethane foam in sizes up to 8" pipe inside 12" pipe all failed. Two-pound C-4 charges detonated within such containers, disintegrated both pipes (only a few fragments of the outer pipes were found) and shredded laboratory coats on scarecrows standing two feet away. The destruction of the protective garb on the scarecrows was brought about, not by fragments, but by the direct effect of the blast. Even had the containers remained intact, their use would not be practical, since personnel would be subjected to grave concussion and noise injuries.

Conclusions

In summation, direct experiments demonstrate the feasibility of protecting laboratory personnel during synthesis, handling and initial scale-up manufacture of explosive materials without the use of elaborate remote equipment or erection of heavy, permanent structures. Small polyurethane containers will confine a couple of grams on the bench and hand-size metal pots can be designed to hold 25 grams. Steel boiler plate shields for laboratory synthesis will protect personnel from upwards of 50 grams of unconfined explosive and we have solved to our satisfaction the problem of manipulating confined charges of a pound. As for portable shields for pound quantities, clearly we shall have to go to complete confinement in some such form as a "thump" box or a heavy spherical container.

Col. Hamilton: The next item on the agenda is "Thermal Decomposition of Unstable Materials" by Dr. C. D. Lind, NOTS, China Lake.

Dr. Lind: I'd like to describe a method of studying the thermal decomposition of unstable materials and a new technique for applying the results one gets from such a study to the prediction

of future thermal behavior of different shapes and quantities of material. The method itself is not new although it hasn't received as much interest as I think it should. The thermal behavior of unstable materials may be studied conveniently using an apparatus designed to allow the material to self-heat under adiabatic conditions. While this method is not new[1-4], a new technique of applying data obtained by the method has made it more important[5].

Several uses of thermal decomposition information may be cited. It can be used to guide the safe handling, processing, and storage of materials. It can be used in the determination of a material's ability to withstand aerodynamic or other heating in actual use.

Another area in which thermal decomposition data may be indirectly applied is that of sensitivity to mechanical shock. Since the impact in a mechanical shock situation imparts insufficient energy to the material as a whole to cause decomposition there must be an energy concentration mechanism involved. All of the theories used to explain this energy concentration require a temperature increase in a small volume, caused by thermal decomposition. This suggests that a better understanding of thermal stability might lead to a correlation with impact sensitivity.

A mass of thermally decomposing material is described by the following expression:

$$-\lambda \nabla^2 T + \rho C \frac{\partial T}{\partial t} = \rho Q Z e^{-E/RT}$$

where:

λ = thermal conductivity
∇^2 = Laplacian operator
T = temperature
ρ = density
C = heat capacity
t = time
Q = heat of decomposition
Z = frequency factor
E = activation energy
R = gas constant

The first term ($-\lambda \nabla^2 T$) involves the temperature profile in the material and is dependent on the heat transfer from the mass. The second term ($\rho C \frac{\partial T}{\partial t}$) involves the heat used to raise the temperature of the material. The third term ($\rho QZ e^{-E/RT}$)

involves the heat evolved by the thermal decomposition. It should be pointed out that the constants λ, C and ρ can be determined by standard laboratory methods but Q, Z and E are more difficult to determine. The expression is important, because if the constants are known, the future thermal behavior of a mass of material can be predicted. For example, it may be predicted whether a given mass of material, in an oven at a certain temperature, will reach a steady state or will ignite.

In an experiment where a material is held either isothermally or adiabatically, the above expression may be simplified. If the material is held isothermally, the second term is zero and the heat transferred must be equal to the heat generated by decomposition. If on the other hand the material is held adiabatically, the first term is zero and the expression simplifies to:

$$\frac{dT}{dt} = \frac{QZ}{C} e^{-E/RT}$$

or:

$$\ln \frac{dT}{dt} = \ln \frac{QZ}{C} = \frac{E}{RT}$$

This suggests that if in an experimental situation there is no heat transfer ($\nabla^2 T = 0$) and if the log of the temperature rise is plotted against the reciprocal of the temperature, a straight line will result. The slope of this line will be equal to $- E/R$ and its intercept equal to $\ln \frac{QZ}{C}$. Thus are yielded those constants which are more difficult to obtain. This analysis forms the basis for the method used.

The above analysis is not involved but the experimental arrangement is more complex. A small cylindrical aluminum furnace 2" in diameter and 6" long has been designed. The furnace has a central sample chamber which holds a sample of about 3 g. and has a compressed air inlet to allow for cooling the sample at the end of the measurement. Heating of the furnace is done by a 600 watt heating element wrapped around the outside. Provision is made to measure and record with thermocouples both the temperature of the furnace and of the sample. In addition a differential thermocouple, one junction of which is in the sample and the other in the furnace measures the difference in temperature between the sample and furnace. This difference is recorded on a recorder which has connected to it an electronic control which controls a power supply which in turn is connected to the heating element of the furnace. The electronic control is arranged to automatically regulate power to the furnace heater so that the furnace temperature maintained is the same as the sample temperature.

In practice the sample is loaded into the furnace. The furnace is heated by manual control to a temperature at which the sample is appreciably decomposing and is then switched to the automatic control mentioned above. The sample is then controlling the temperature of the furnace and since the sample and furnace are at the same temperature, there is no heat transfer. Thus all of the heat generated by the decomposition is used to raise the temperature of the sample. One of the results of the experiment is immediately available at this point. Since there is no heat transfer, the temperature record of the self heating of the sample describes the behavior of an infinite size sample and can be used as a guide for handling very large masses of the material.

The sample is allowed to self-heat until the heating rate is approximately 0.5°C/min. The furnace heater is then shut off and if the sample does not start to cool the air is turned on to cool the sample. By this means the sample is prevented from igniting and can be re-run to determine if it changes during measurement or if there are any autocatalytic effects. To analyze the experimental data the slope of the self heating curve is determined at various temperatures and the log of this slope is plotted vs the reciprocal of the temperature. According to the theoretical equations, this second curve is a straight line with a slope equal to $-E/R$ and an intercept equal to log $\frac{QZ}{C}$. Thus this experiment yields those constants needed for the kinetic equation which are difficult to obtain.

It was implied in the beginning of this paper that if the constants were known and the thermal equation were solved, valid predictions of future thermal behavior could be made. Since the equation is a strongly non-linear differential equation, the solution is mathematically complex, however, it has been solved analytically for the critical temperature. The critical temperature is the maximum surface temperature a mass of material can have and still maintain a steady state (not self heat to ignition). The equation has also been solved by numerical methods for the time to ignition. This is the time it takes for a given mass of material to ignite if placed in an environment higher than its critical temperature.

The use of the equations either to find the critical temperature or the time to ignition are somewhat laborous. Recently Longwell has devised a set of three nomographs which greatly simplify the use of the equations. Thus with a knowledge of the constants of the material and the geometry of the mass involved, the nomographs can be used to predict if the mass will ignite under given conditions and if so how long it will take.

REFERENCES

1. H. Henkin, "Kinetics of Decomposition of Various Explosives," OSRD 3856, July 1944 (Conf.).

2. W. H. Rasking and A. F. Robertson, Rev. Sci. Instr., 25, 541 (1954).

3. K. G. Scrogham, "Lab Techniques for the Determination of Thermal Stability," Bulletin of the Joint Meeting, JANAF Panel on Physical Properties and Surveillance of Solid Propellants, 20 Sept. 1960 (Conf.).

4. D. Gross and A. B. Amster, "Adiabatic Self-Heating of Several Explosives and Propellants," 8th Symposium on Combustion, 28 August 1960.

5. P. A. Longwell, "The Calculation of Critical Temperatures and Time to Explosion of Propellants and Explosives," NAVWEPS 7646, Sept. 1961.

6. C. D. Lind, "The Thermal Decomposition of Explosives, NavWeps 7798, October 1961.

Col. Hamilton: Thank you very much Dr. Lind. The next presentation will be "Desensitization of Zirconium to Electrostatic Discharge" by Dr. George Rice, NOTS China Lake.

Dr. Rice: The work that I will report today was done by myself and by R. L. Dow who is now with Union Carbide back in Charleston, W. Va. I thought that first I might go a little bit into the reason for being interested in zirconium metal. This talk is classified Confidential.

The use of dense active metal fuels in propellants appears very attractive for first stage application where there is a large ratio of mass-at-burnout to volume-of-propellant, particularly in volume limited situations. Propellant actuated devices, such as personnel ejectors in which the mass-to-volume ratios are also extremely high, would effectively utilize a good dense propellant. This is apparent from consideration of a simplified equation for velocity at burnout (Slide 1):

$$BV = gI_{sp} \ln(1 + \frac{\rho}{M/V})$$

where
g = gravitational constant
I_{sp} = specific impulse of propellant
ρ = density of propellant
M = mass at burnout
V = volume of propellant

Comparing two propellants we then have:

$$\text{Relative BV} = \frac{BV_1}{BV_2} = \frac{gI_{sp1} \ln(1 + \frac{\rho_1}{M/V})}{gI_{sp2} \ln(1 + \frac{\rho_2}{M/V})}$$

Figure 1 (Slide 2) gives a comparison on this basis of two propellants, one dense and one high specific impulse. At mass-to-volume ratios above 35 pounds at burnout per cubic foot of propellant, the dense propellant gives better performance.

With a very large mass-to-volume ratio the quantity $\frac{\rho}{M/V}$ becomes small and for $\ln(1 + x)$ with x a small number we may substitute x. Thus at very large mass-to-volume ratios the relative burnout velocities of candidate propellants can be compared by consideration of the products of the propellant density and specific impulse:

$$\text{Relative BV} = \frac{Isp_1 \rho_1}{Isp_2 \rho_2}$$

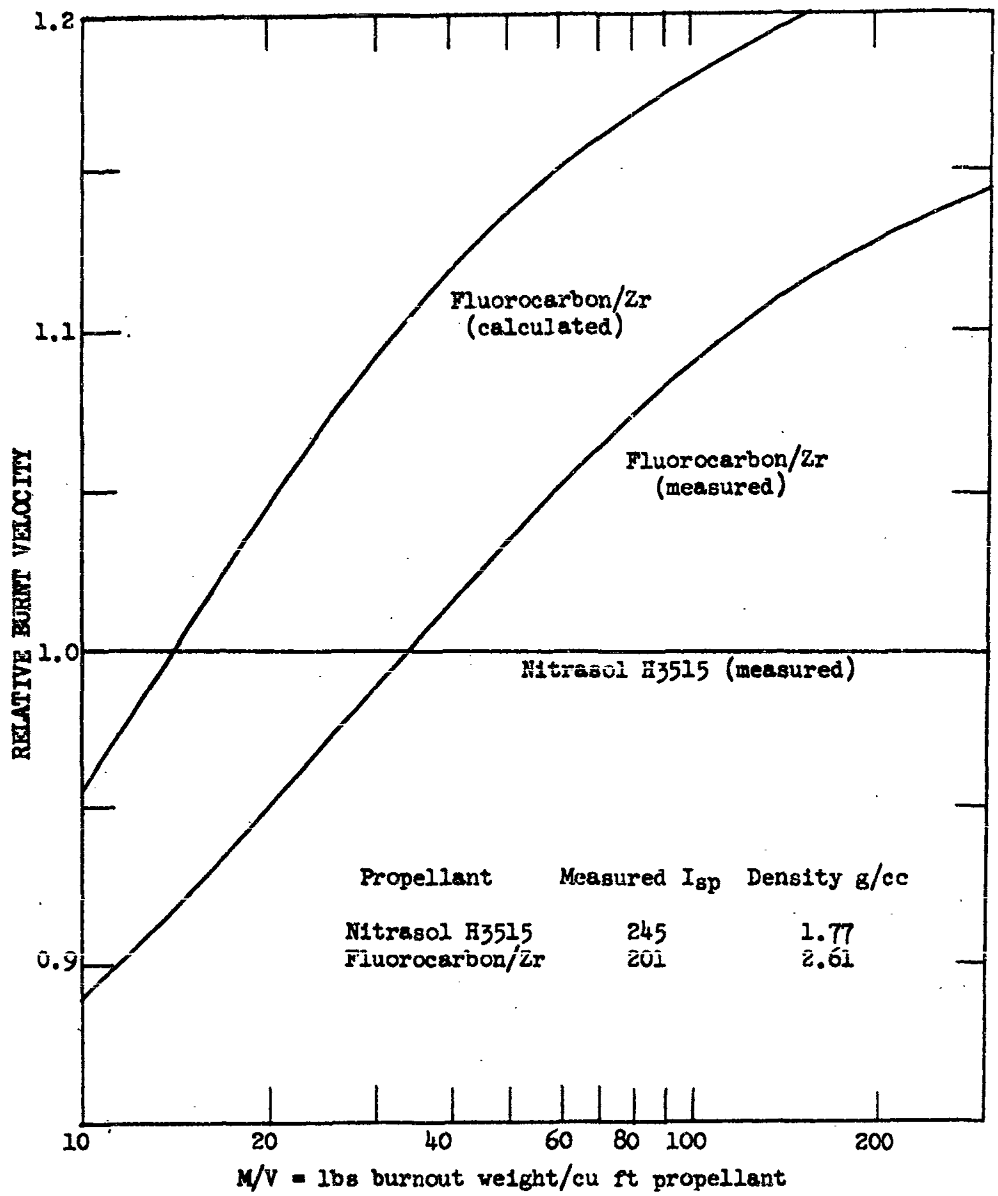


FIG. 1. Relative Burnt Velocity at Burnout of a Dense Propellant Compared to Nitrasol H3515.

Using this expression, performance comparison for metal fuels may be made on the basis of the heats for formation of the expected reaction products and the densities of the elements. Henderson & Rumbel have discussed and tabulated these indices of performance (1). Considering oxygen systems, Table 1 (Slide 3) compares these values for three candidate dense fuels with those for aluminum. The heat of formation/gram for each metal is an index of specific impulse. The column labeled Kcal/cc then is an index of burnout velocity at large mass-to-volume ratios. Thus the three dense active metals titanium, zirconium, and thorium would appear to be better fuels in oxygen systems than aluminum in those applications having large mass-to-volume ratios. Zirconium appears somewhat superior to the other two.

TABLE 1: PROPERTIES OF SOME METALS OF INTEREST AS DENSE FUELS.

Element	Atomic Weight	Density g/cc	Oxide	Heat of Formation of the Oxide Kcal/mole	Kcal/g	Kcal/cc
Al	26.97	2.70	Al_2O_3	380	3.7	10.0
Ti	47.90	4.5	TiO_2	216	2.7	12.2
Zr	91.22	6.5	ZrO_2	258	2.18	14.2
Th	232.12	11.2	ThO_2	293	1.26	14.1

The availability of high purity zirconium and the absence of radiological and toxicity problems has focused considerable interest on zirconium metal powder as a propellant fuel. It has of course been realized that special attention must be given to the handling of the powdered metal in view of the extensive history of accidents and incidents involving zirconium in recent years. These have been reviewed (2, 3, 4) and findings indicate that the low ignition temperatures and the associated extreme sensitivity to electrostatic discharge have been primarily responsible for the reputation of zirconium. Flammability and explosion tests conducted by Hartmann at the Bureau of Mines, for example, have shown that zirconium was the only metal tested which ignited at room temperature when a cloud of metal dust was blown into a special furnace (5). This was attributed to the electrostatic sensitivity of the fine metal dust. The same investigators, in further studies, determined electrostatic sensitivities of their zirconium samples as ranging upwards from 40,000 ergs (6), and they have calculated that electrostatic spark energies of the order of 100,000 ergs might be built up and discharged from a human body to ground under certain conditions (7). Anderson and Belz (8) concluded, from studies

of sensitivity as a function of particle size, that below approximately 10 microns diameter dry zirconium powder cannot be handled without danger of ignition by static discharge. It should be stressed, however, that there are many factors affecting sensitivity besides particle size or surface area: particle shape, particle size distribution, sample mass, impurities, aging of sample, alloying, distribution of impurities within the particles, humidity, air, etc. (8).

Among the methods that have been suggested for the desensitization of zirconium metal powder are 1) coating with copper by displacement plating (6); 2) coating with mineral oil (9); 3) coating with polystyrene (10); 4) passivation of surface by treating with carbon tetrachloride (2); 5) formation of oxide film by exposure to the air (11); and 6) the elimination of the fine particles by improved processing procedures or by elutriation. More recently, workers at Frankford Arsenal have successfully desensitized zirconium powders by the formation of a thin coating of zirconium hydride on the surface by treatment of the metal with 1% hydrofluoric acid. The hydrogen is generated by the reaction: $Zr + 3H_2F_2 \rightarrow H_2ZrF_6 + 2H_2$

We have been conducting experiments with two zirconium metal powders. The first of these we obtain from Carborundum Metals Co. It is made by the Kroll reduction process and contains about 2% magnesium. Figure 2 (Slide 4) is a scale indicating the magnification used in photographing a sample of this material as shown in Figure 3 (Slide 5). It is ground to an average particle size of about 22 micron diameter with less than 20% greater than 30 microns, none greater than 100 microns; and with 2.7% less than 8 microns, none less than 5 microns. We receive the metal in sealed flasks under argon; these we open in the air at the time of use. We have found that the various lots of this material have electrostatic sensitivities in the range of 100,000 to 200,000 ergs and thus can be handled without pretreatment, but with very strict regard for all safety precautions specified for electrostatic sensitive materials: 1) equipment, vessels, and mixers are grounded; 2) sparkless conducting vessels and tools are used; 3) conductive shoes that are tested regularly and protective cotton clothing are worn; and 4) the floors of the mixing bay are conductive and wet. These precautions are of course taken in addition to the usual precautions to be followed dependent on the type of propellant and size of the propellant lot.

However, there are possible advantages in being able to use a small particle diameter zirconium. Most important perhaps is the possibility of improving combustion efficiency and thereby increasing delivered specific impulse. Other reasons would

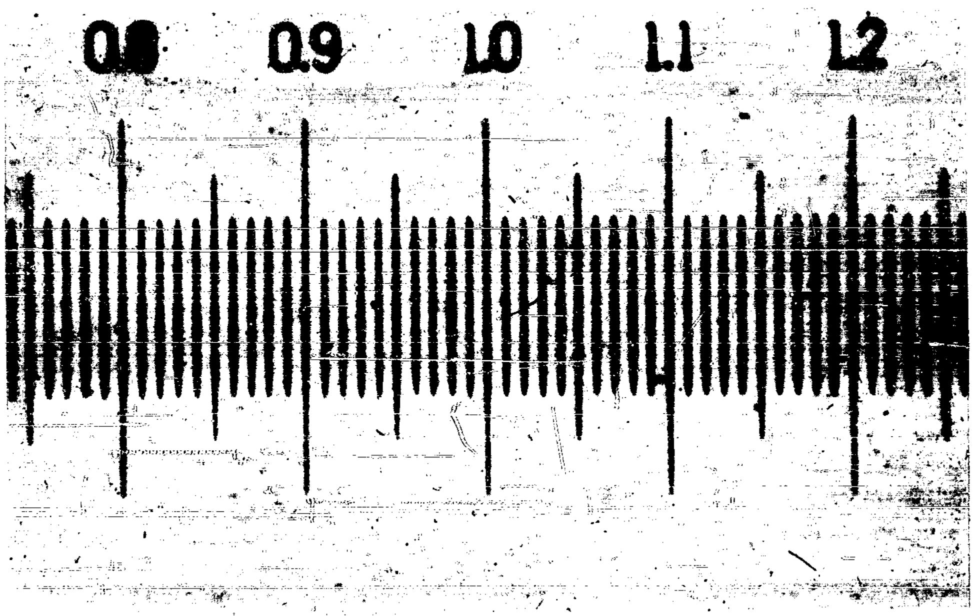


Figure 2

Scale for Photomicrographs, 10 microns per scale division.

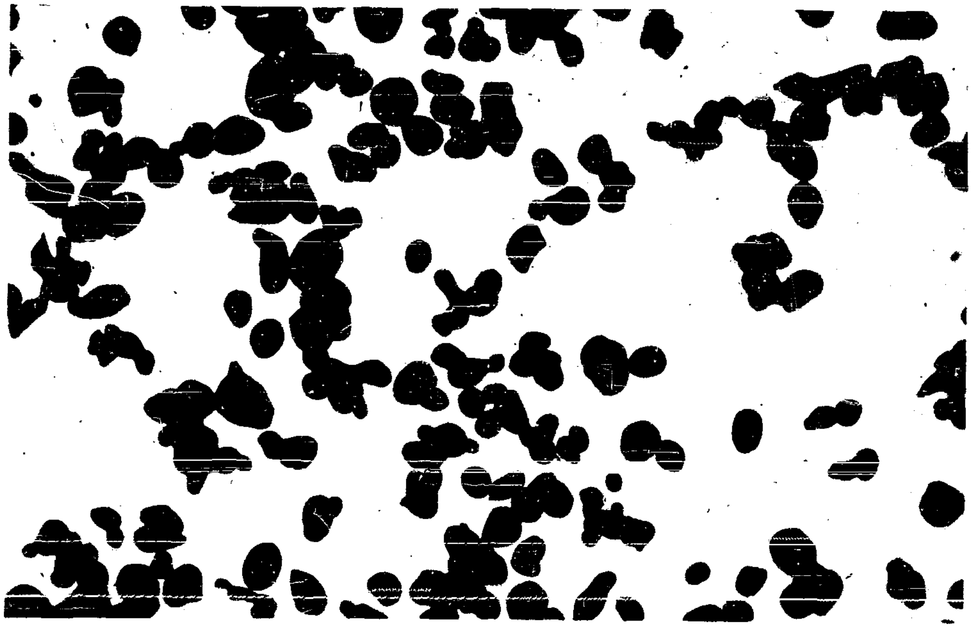


Figure 3

Zirconium metal powder of 22 micron average particle diameter.

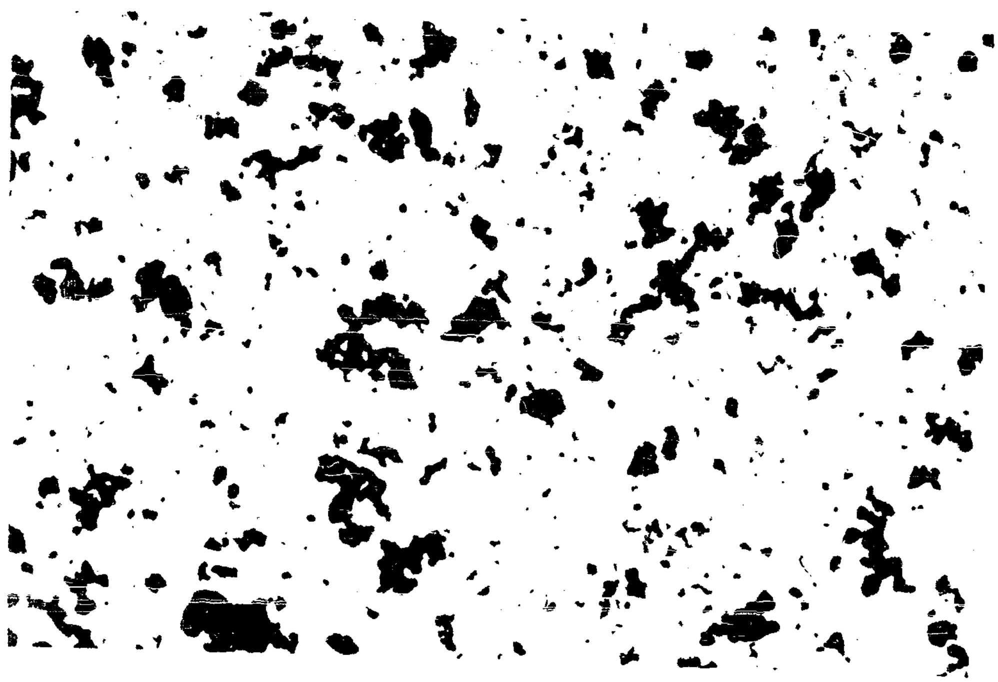


Figure 4

Zirconium metal powder of 5 micron average particle diameter.

include modification of ballistic properties of zirconium propellants as well as those containing other metal fuels. The second zirconium metal powder that we have obtained for our studies has an average particle diameter of 4-6 microns as shown in Figure 4 (Slide 6). It is produced by Metal Hydrides Inc. and is their grade Z. We receive the metal packaged with a minimum of 25% water and the company recommends that this level be maintained during storage. Because of the irregular shape of the powder and the accompanying high surface area, the electrostatic sensitivity of the dry powder is very high.

Sensitivities to electrostatic discharge of these two zirconium metal powders and of other metal powders for comparison are given in Table 2 (Slide 7). Note that thorium is quite sensitive.

TABLE 2: SENSITIVITY TO ELECTROSTATIC DISCHARGE OF METALS OF INTEREST AS DENSE PROPELLANT FUELS

Metal	Particle Size	Electrostatic Sensitivity 50% point, ergs
Ti	44µ and under (-325 mesh)	1,000,000-4,000,000
Th	30µ and under (-425 mesh)	30,000-40,000
Zr	22µ	100,000-200,000
	5µ	700-3,000
Zr-Al alloy	22µ	300,000-400,000

We have attempted desensitization of the extremely sensitive 5 micron diameter zirconium by three methods which appeared feasible in the intended application. These were: 1) displacement plating with nickel, 2) coating with polymer by a shock-gel procedure, and 3) coating by direct application of surface active materials.

The application of nickel by displacement plating on massive zirconium had been developed by Cain for the AEC (13). We adapted his procedure to the plating of nickel on finely divided zirconium metal as follows:

> Dissolve 50 grams $NiCl_2 \cdot 6H_2O$ and 10 grams sodium acetate in one liter of water containing 6 cc of 48% hydrofluoric acid. Place 100 grams of the water-wet as-received zirconium powder (Metal Hydrides, Inc., Grade Z) on fine

filter paper in a Buchner funnel and slowly pour the solution over the zirconium. Adequate ventilation is necessary to remove the hydrogen gas formed. Wash the plated zirconium with water and dry it for use.

Analyses vary from one run to the next due to different contact times. A typical run following the above procedure gave 3.6% coating of nickel. Results of electrostatic sensitivity measurements indicated that a 4% coating of nickel was the least that would be required to decrease the sensitivity to 100,000-200,000 ergs or greater. Therefore this technique has not been further pursued.

Polymer coatings of a nylon (Zytel 63), a polyvinyl alcohol, and Viton A have been successfully applied by a slurry or shock-gel method. Nitrocellulose did not give a good coating but this material may be of further interest. The procedure is as follows:

Weigh out the desired quantity of water-wet zirconium. Remove the water by washing with dry solvent and decanting. Add the solution of polymer in solvent and stir the slurry vigorously in an explosion-proof Waring Blendor during the rapid addition of non-solvent. Allow the solids to settle and pour off and discard the supernatant. Wash once or twice by adding non-solvent and stirring vigorously in the Waring Blender a short period of time. Dry the solid for use.

Our results with Viton A, using acetone as the solvent and hexane as the non-solvent, were encouraging from the stand-point of reproducibility. Further, the product was a free-flowing powder at Viton A levels of 3-4 wt-%, levels which were effective in passivation of the surface to electrostatic discharge as shown in Table 3 (Slide 8) and Figure 5 (Slide 9).

TABLE 3: DESENSITIZATION OF 5μ ZIRCONIUM METAL TO ELECTROSTATIC DISCHARGE BY COATING OF VITON A

Wt % coating of Viton A	Electrostatic sensitivity 50% point, ergs	
0.0	920	1,370
1.0	5,150	5,760
3.0	83,000	105,000
10.0	no data	3,000,000

A third treatment which we have used has been the application of surface active agents to the finely divided zirconium powder. A number of proprietary emulsifiers were tried and of

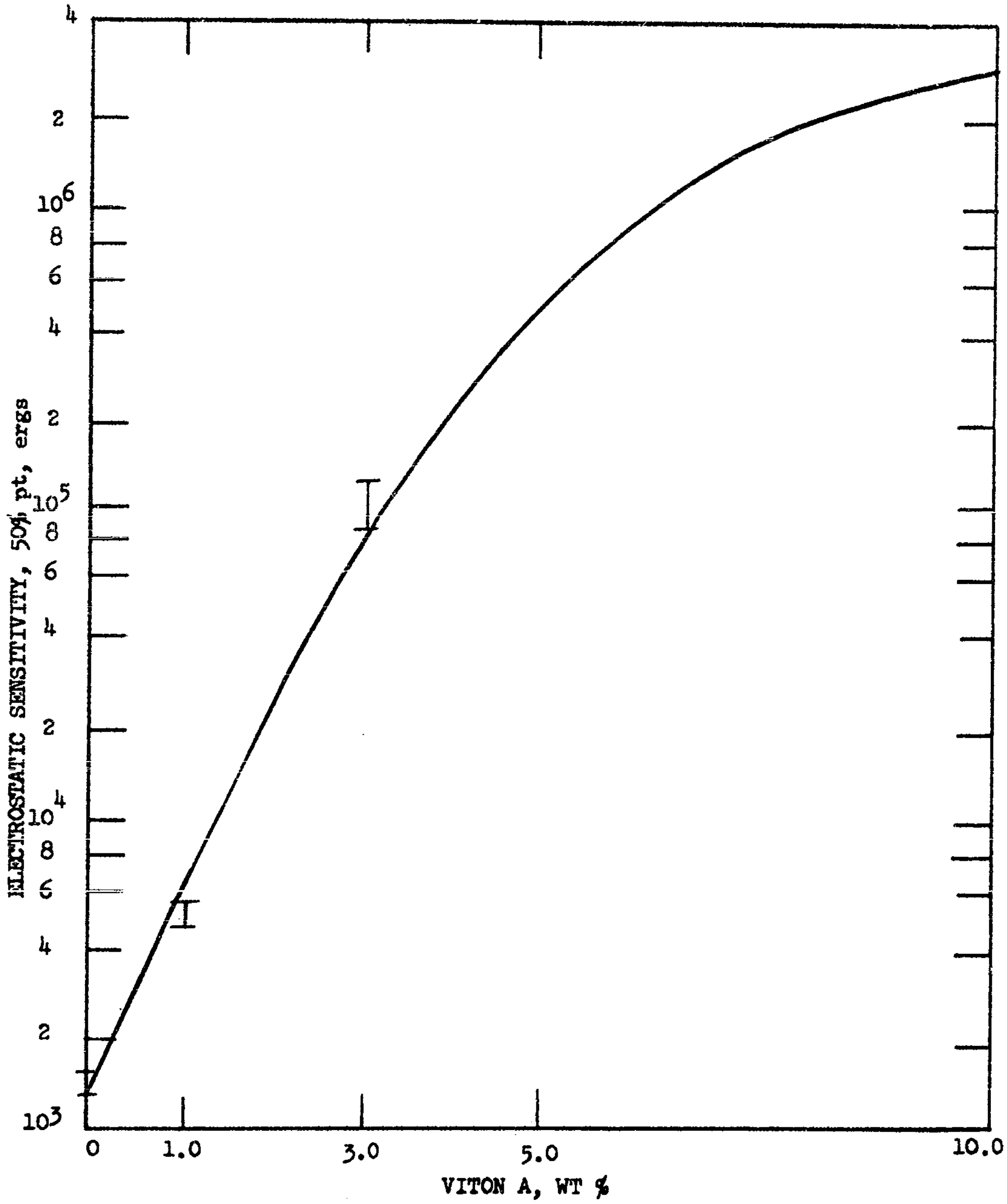


FIG. 5. Desensitization of 5μ Zirconium Metal to Electrostatic Discharge by Coating with Viton A.

these, an oil-in-water emulsifier, Alkaterge-T, marketed by Commercial Solvents Corporation, exhibited excellent desensitizing properties. The procedure for its application is:

> Weigh out water-wet zirconium in a suitable container. Weigh out Alkaterge-T equal to 1 wt-% of the zirconium and dissolve it in hexane in the ratio of 25 ml of hexane to 1 gram emulsifier. Add enough water to the zirconium to obtain a thick flowing slurry. Add the emulsifier solution to the zirconium slurry with stirring and continue stirring until a thick lump-free mixture results. Dry the mixture at 75° C. During the drying, break up the cake occassionally to get a more uniform product.

Results of three different runs are given in Table 4 (Slide 10) and Figure 6 (Slide 11). Electrostatic sensitivities at levels of 1 wt-% emulsifier appear satisfactory. Ten pounds of 5µ Grade Z zirconium treated by this procedure gave a product with an electrostatic sensitivity range of 90,000 to 140,000 ergs.

TABLE 4: DESENSITIZATION OF 5µ ZIRCONIUM METAL TO ELECTROSTATIC DISCHARGE BY COATING OF ALKATERGE-T

Wt % coating of Alkaterge-T	Electrostatic Sensitivity 50% point, ergs		
0.0	1,460	1,190	1,100
0.5	17,600	18,100	11,600
1.0	73,100	56,300	103,000
2.0	231,000	269,000	412,000
4.0	1,620,000	1,920,000	1,950,000

In studies of zirconium-containing solid propellants, we have employed two systems, a cast energetic binder and an extruded stable binder. In each case, ammonium perchlorate has been utilized as the oxidizer. The cast system is based on the Nitrasol-PA binder, a mixture of plastisol nitrocellulose with trimethylolethanetri-nitrate (TMETN) and triethyleneglycoldinitrate (TEGN) as plasticizers and resorcinol as stabilizer. The general procedure for mixing and casting is the same as that employed for the aluminized propellant. With the 22 micron diameter zirconium we use no pretreatment of the metal powder; the 5 micron diameter zirconium has been coated with 1 wt-% Alkaterge-T. Sensitivity of the cured propellant (cure temperature 65° C) has been similar to that of the aluminized. The effect of substitution of 5µ zirconium for all or part of the 22µ has been to increase the burning rate and pressure exponent as shown in Figures 7 and 8 (Slides 14 and 15). The effect on impulse efficiency has not yet been tested by the firing of experimental motors.

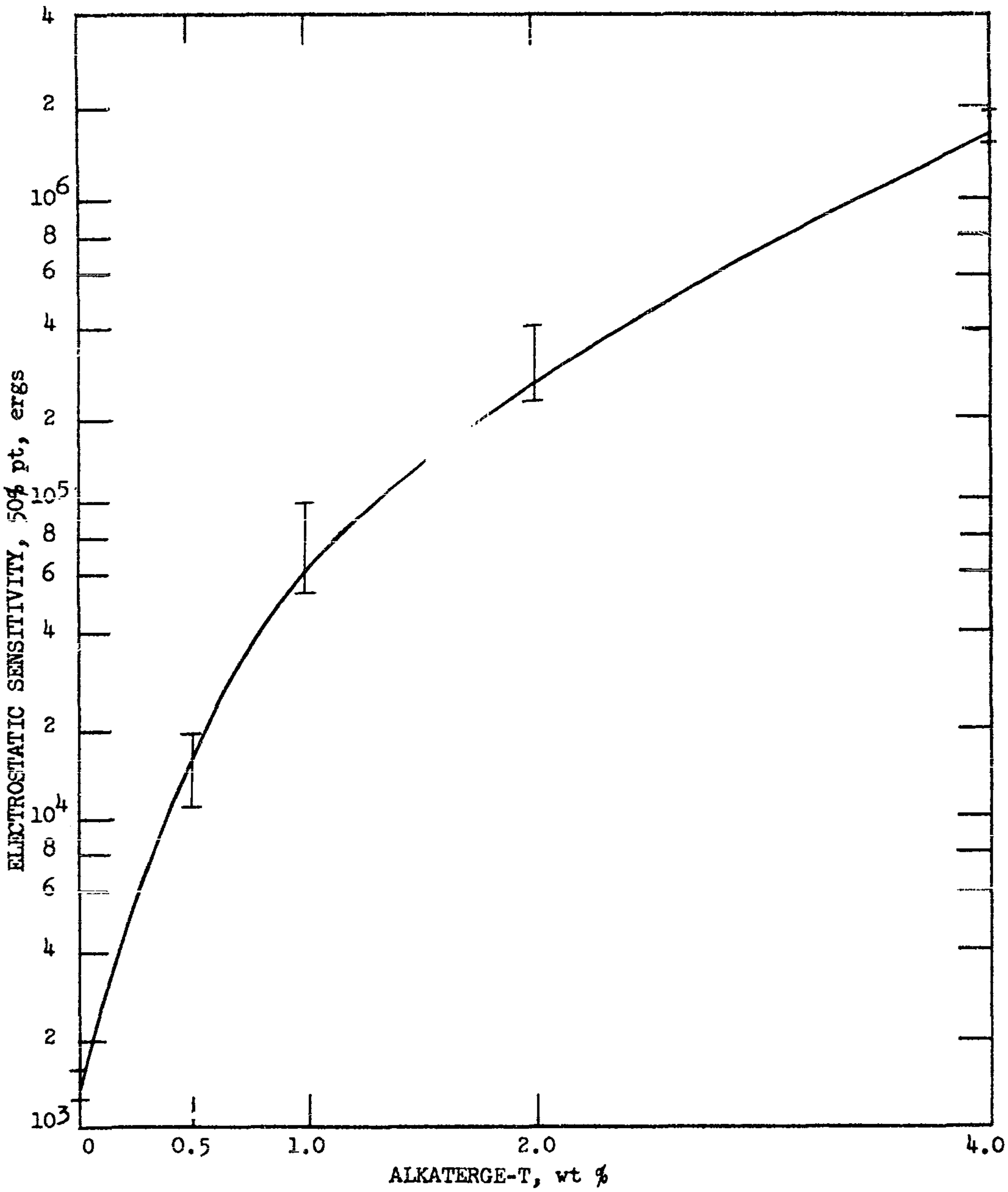


FIG. 6. Desensitization of 5μ Zirconium Metal to Electrostatic Discharge by Coating with Alkaterge-T.

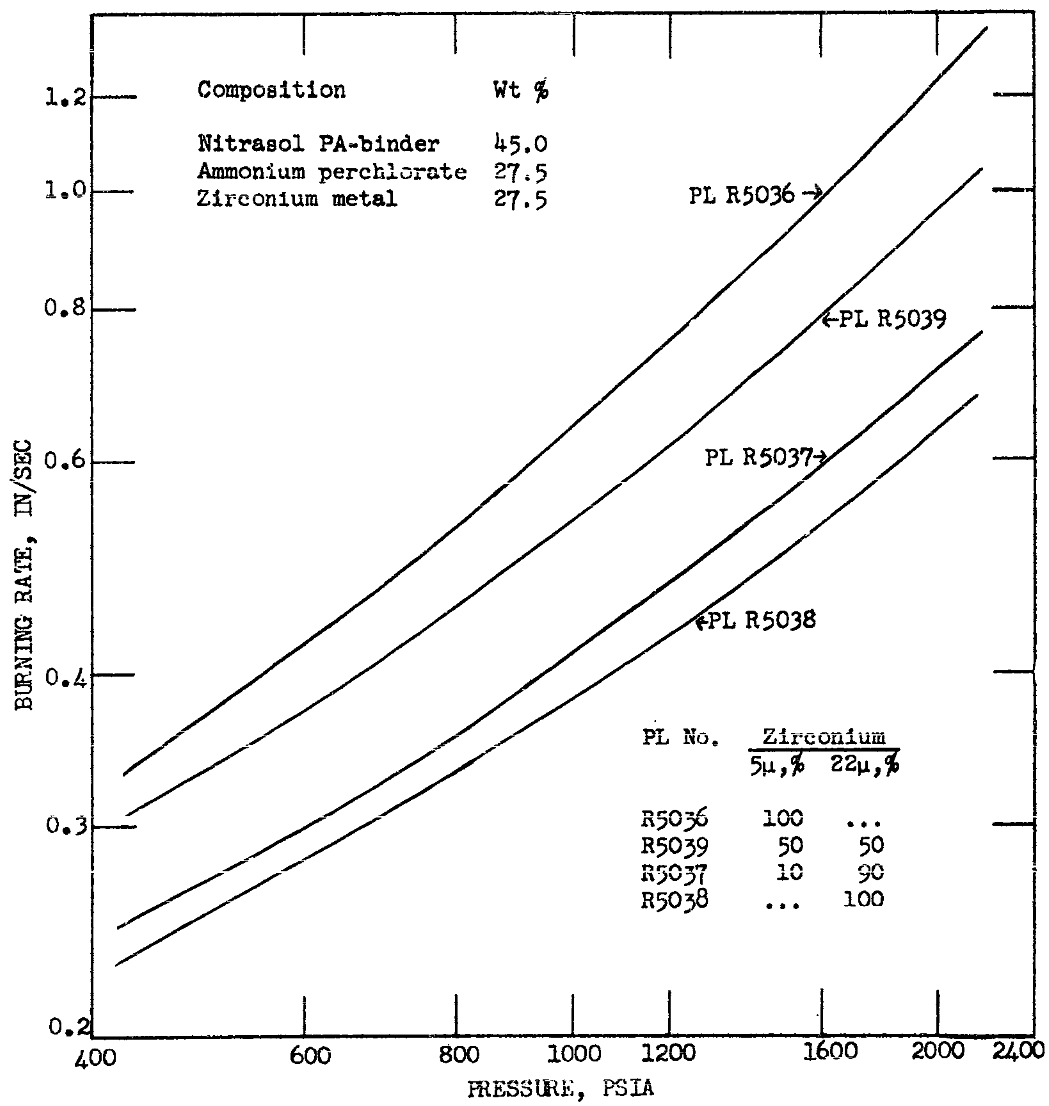


FIG. 7. Effect of Particle Size of Zirconium Metal on Burning Rate of a Nitrasol Propellant at 70°F.

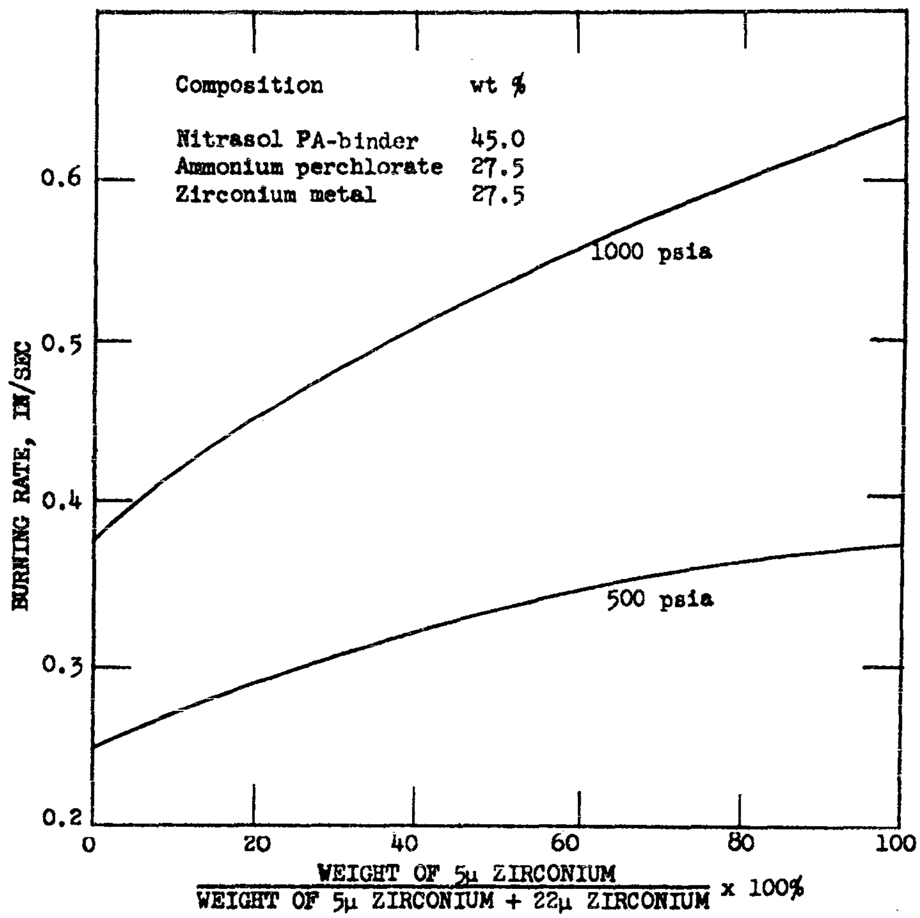


FIG. 9. Effect of Particle Size of Zirconium Metal on Burning Rate at 500 and 1000 psia of a Nitrasol Propellant at 70°F.

The extruded system undergoing evaluation with zirconium is one having a Teflon/Viton A binder system. The propellant molding powder is prepared by the shock-gel process. The Teflon and ammonium perchlorate are slurried in an acetone solution of Viton A. Since acetone is employed in the procedure we have wet the 22μ zirconium with acetone immediately following the weighing and have then added it directly to the slurry vessel. In the case of the 5μ water-wet zirconium, we have washed out the water by decantation with acetone before addition to the slurry vessel. A large volume of hexane is added to the acetone slurry to shock-gel the Viton A onto the solids present. The liquid supernatant is then decanted and the solids washed several times with hexane, air-dried, and vacuum dried. The free-flowing molding composition is then ready for extrusion. Sensitivity of the zirconium molding composition has been similar to that of the aluminized. In this procedure, the zirconium is essentially desensitized by being wet throughout the mixing process and by its coat of Viton A in the final molding powder. The effect of substitution of 5μ zirconium for all of the 22μ has been to increase the burning rate strikingly without modifying the pressure exponent. This is shown in Figure 9 (Slide 17).

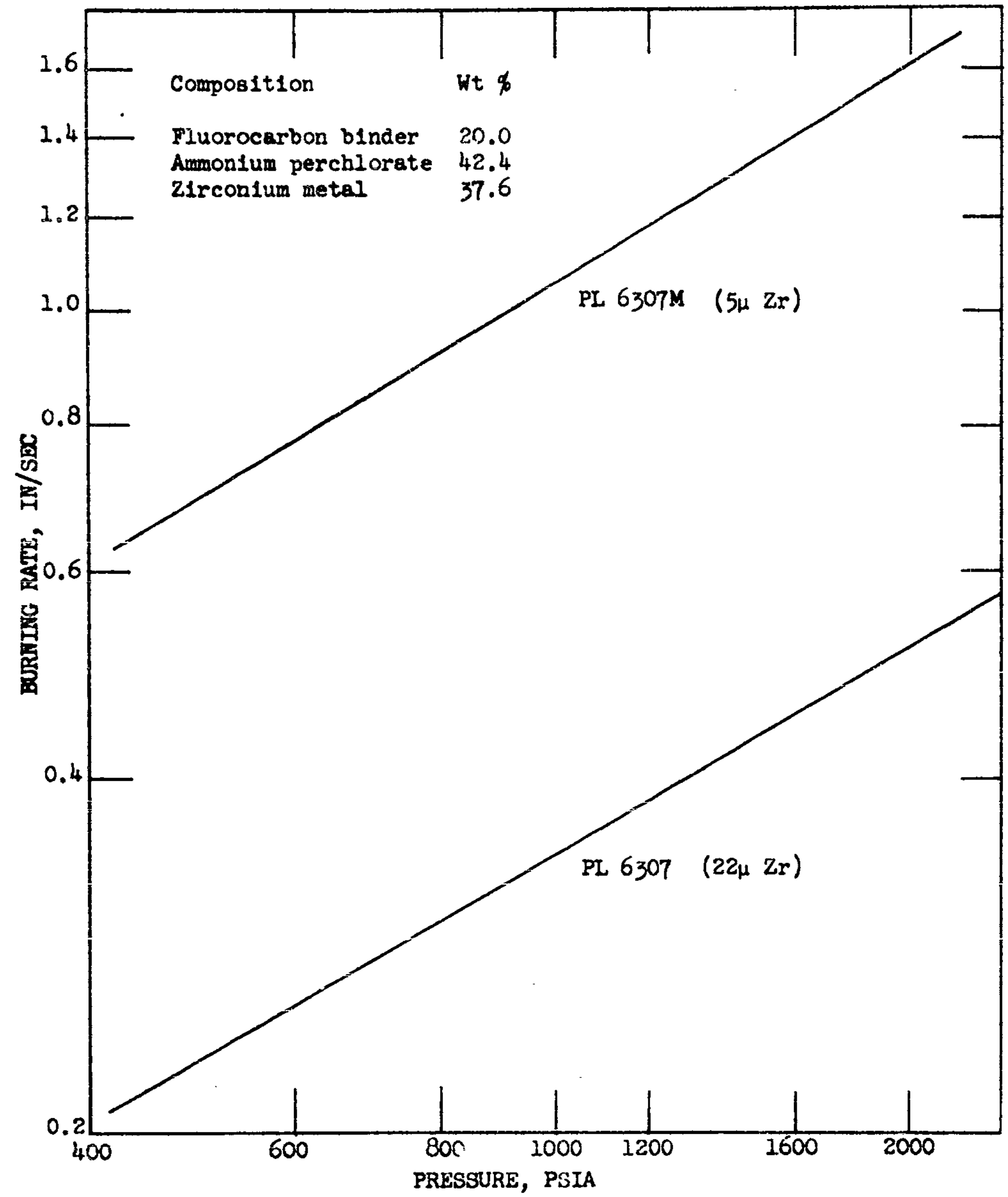


FIG. 9. Effect of Particle Size of Zirconium Metal on Burning Rate of a Fluorocarbon Propellant at 70°F.

BIBLIOGRAPHY

1. K. E. Rumbel, C. B. Henderson, and E. F. Rosholdt, Atlantic Research Corporation Quarterly Progress Report No. 25, Co Contracts NOrd-15536, 16577, 16842, pp. 28-33, Nov. 1956. CONF

2. Safety and Fire Protection Branch, Division of Organization and Personnel, U. S. Atomic Energy Commission, "Zirconium Fire and Explosion Hazard Evaluation," Interim Report, TID 5365, Aug. 1956, AEC Technical Information Service Extension, Oak Ridge, Tenn.

3. E. L. Stout, "Safety Considerations for Handling Plutonium, Uranium, Thorium, the Alkali Metals, Zirconium, Titanium, Magnesium, and Calcium," LA 2147, 1958, Los Alamos Scientific Laboratory of the University of California, Los Alamos, N. M.

4. W. R. DeHollander, "An Evaluation of the Zirconium Hazard," HW-44989, Aug. 1946, Hanford Atomic Products Operation, General Electric, Richland, Wash.

5. I. Hartmann, J. Nagy, and H. R. Brown, U. S. Bureau of Mines, Report of Investigations 3722, Oct. 1943.

6. I. Hartmann, J. Nagy, and M. Jacobson, U. S. Bureau of Mines, Report of Investigations 4835, 1951.

7. I. Hartmann, Ind. Eng. Chem., 40, 752 (1948)

8. H. C. Andersen and L. H. Belz, J. Electrochem. Soc., 100, 240 (1953).

9. Communication from Alleghany Ballistic Laboratory, Hercules Powder Company, Cumberland, Md.

10. B. Kopelman and V.B. Compton, Metal prog., 63, 77 (1953).

11. Communication from Carborundum Metals Co., Akron, N. Y.

12. P. Karlowicz, G. Norwitz, and J. Cohen, J. Electrochem. Soc., 108, 659 (1961).

13. F. M. Cain, Bettis Technical Review, WAPD-BT-6, pp. 48-57 (1958).

Col. Hamilton: Thank you Dr. Rice. Any questions?

Dr. M. B. Frankel, Stanford Research Institute: How does the zirconium hydride compare to zirconium powder as far as the electrostatic sensitivity is concerned and it's influence on boost velocity?

Dr. Rice: The zirconium hydride sensitivity is much less. It can be handled safely, however, the boost velocities are 3 to 5% lower as I remember the curves. They're lower all the way. This is in nitrosol and in fluro-carbon binder systems.

Mr. Visnov: As you indicated, we have been using fine zirconium powders for quite some time. I have two quick comments, one from the point of view of safety. Your use of wetting agent in the water may prevent someone from getting seriously hurt. I personally have had experience of a container of fine zirconium powder that was underwater when the water was decanted, the top layer just looked like gray mud. When we removed that, it was a little dryer and as we went deeper we found that the bottom of the container, that zirconium dust was completely dry, there was no wetting agent. So we sent it up for electrostatic discharge, the results showed that we would have gotten a very violent surprise if we assumed we were working with wet zirconium powder. So I would suggest that your use of a wetting agent in your water is also a little more insurance that you've got wet zirconium powder and not possibly a dry mix. The second point I wanted to make was you mentioned the use of a micromirograph and you were trying to find out what the particle sizes were, your slide showed a very random type slate. I once had to determine this at least four or five years ago, the results were very bad. I never knew it was solved yet any particle size system that depends on Stokes Law depends on the sphere and the more you deviate from the sphere your results are just off. You simply don't know what size zirconium powder you're working with.

Dr. Rice: The photograph is perhaps the best method. I had a film made of various of these preparations, zirconium preparations burning. I had ignited them by electrostatic spark and the film was not ready in time but it did show the effect of water on burning and this is very bad. The burning takes place almost explosively. With the various coatings that we put on, the coating material has ignited and burned very smoothly. Then finally the zirconium catches and burns, but it's not violent. It's a controlled reaction, I think that we could safely turn around and walk away. It's water that's dangerous with zirconium.

Col. Hamilton: Thank you very much Dr. Rice. Our next speaker is Dr. Dwight Culver, Medical Director of the Aerojet-General Corp., Azusa. Dr. Culver will speak on "Toxic Hazards."

Dr. Culver: There is remarkably little in the way of literature on the subject of solid propellant toxicology. This situation is not surprising. Solid propellants are mixtures of very large numbers of ingredients in almost infinite numbers of combinations. Such variety makes it difficult to put together a comprehensive discussion of the toxicology of solid propellants. Secondly, companies are extremely reluctant to release data on their formulations. Despite these difficulties, I think it may be worthwhile to try to discuss on a general basis the problems of solid propellant toxicity and some specific ingredients. As a background for this discussion, it will be helpful for me to put propellant formulation in a somewhat orderly arrangement, reviewing as well as we can the various categories of ingredients.

A solid propellant is usually made up of the following ingredients: oxidizer, binder, fuel, and additives. The fuel and oxidizer are held together in a binder matrix, producing a plastic mass. Additives are mixed in at the time of formulation to modify either the elastic properties of the mass, the burning rate, or the visual characteristics of the end product. Once the various ingredients have been cast into a grain and the binding material has polymerized, the end product has been considered to be of relatively low toxicity. Later in this discussion, considerations of epoxy systems will indicate that this concept should be modified. However, primary consideration must be given to the separate ingredients and some mention made of exhaust products. Hazards exist during formulation where potential exposures may occur. Toxic exposures are reduced by the requirement for fairly complete remote operation of blenders and mixers because of explosion and fire hazards. The weighing and transfer of the separate ingredients into the blenders does occasionally result in exposure.

First to be considered are the epoxy binders. They have acquired a reputation for being difficult to handle, producing a high incidence of skin disease. The curing or hardening of this type of plastic is frequently accelerated with amine catalysts. Amines have been found to be responsible for skin sensitization more often than have the epoxy monomers. Studies done in England and in this country have shown that even the cured resin still contains some unreacted amine and cases of dermatitis, as well as pulmonary disease, have resulted from exposure to the solidified material. This is at variance with the often repeated statement that cured plastics constitute no problem.

Another binder system is that of the fluorocarbons, such as Viton-A. Most of the high mollecular weight fluorocarbons are relatively biologically inert. The addition of Diamine curing

agents to some of these fluorocarbons gives off hydrogen fluoride, a gas of high toxicity affecting primarily the upper respiratory tract.

Polyurethane binder systems frequently use Toluene 2,4 diisocyanate, a material that has a low acute toxicity but a high capacity for producing sensitization of the respiratory passages. Large numbers of cases resembling asthmatic attacks have been reported among workers using this material. No problems have been reported from workers handling the cured polyurethane plastics.

Binders being considered for future use containing nitrogen fluorine groups are now being studied toxicologically, and very little information is available on these materials. However, it is probable from very preliminary evaluation that the nitrogen fluorine radical is toxic.

Fuels for solid propellants are principally light metals or light element hydrides. The one in most use today is powdered metallic aluminum. Aluminum has generally been considered to be a material having no toxic properties, and, in fact, powdered aluminum has been used by inhalation as a preventive or treatment of silicosis. However, many cases of pulmonary disease were reported in Germany during WW II among men making aluminum powder for munitions. This disease resulted in fibrosis and collapse of the affected lungs. Six cases, two fatal, among thirty workers engaged in making very fine aluminum powder for fireworks in England were reported recently. It would appear that particle size, shape and purity of the aluminum powder greatly affects the potential toxicity of aluminum dust. Aluminum powder used for propellant formulation is produced by spraying molten aluminum through ceramic jets, producing spherical particles. I am unaware of any cases of pulmonary disease from aluminum exposure in the rocket propellant industry. The spherical shape of the aluminum particles may account for this.

Metallic beryllium has been considered by the propellant industry to be potentially a means of breaking through the specific impulse barrier in solid propellants. Fear of the toxicity of beryllium and its compounds has delayed beryllium's use. The great apprehension and strong emotional responses produced whenever the word beryllium is mentioned in connection with propellants result primarily from the lack of knowledge about the conditions of exposure which produce beryllium disease. Beryllium disease can be roughly broken down into two separate entities--the acute disease and the chronic disease. The acute disease is apparently the result of direct chemical action and the inhibition of enzyme systems involved in carbohydrate metabolism.

There is a fairly clearcut dose response relationship present in the acute disease and, although the relative hazards for the various beryllium compounds have not been completely worked out, there appears to be a general relationship between the solubility of the compound in body fluids and the level of toxicity for acute effects.

The chronic disease is much less predictable, in that there is no evident exposure-response relationship. Some people work for many years in high concentrations with no apparent damage. Other people have developed chronic disease manifested by progressive pulmonary destruction after being exposed to extremely low concentrations and for only short periods of time. Workers such as Sterner and Eisenbud have postulated that chronic berylliosis is a result of sensitization in the form of an antigen-antibody reaction. This probably best explains the unpredictable nature of chronic beryllium disease.

The maximum acceptable concentration for faily exposure to beryllium was set rather arbitrarily at two micrograms per cubic meter. Since its establishment over ten years ago no clinical or environmental data have been brought forth which would either provide a basis for changing this level or provide a basis for maintaining this level. It is frequently stated that the companies involved in the production of beryllium have been operating for the past few years at levels in excess of the maximum acceptable concentration, and that no cases of chronic disease have occurred. This is often used as justification for relaxing the precautions to be taken in handling beryllium. Such reasoning, however, is patently fallacious. The longest period between exposure and onset of symptoms, to my knowledge, is in the order of 18 years. There is the possibility that the length of the period between exposure and onset of symptoms is inversely proportional to the magnitude of exposure. Thus, we can extract no reassurance from the statements that workers during recent years exposed to levels above the maximum acceptable concentration have not developed disease. Until more reliable information can be obtained on the mechanism of chronic beryllium disease, we must commit ourselves to operations which limit exposure to the levels recommended by the Beryllium Advisory Committee of the Atomic Energy Commission. In actual practice, these levels impose no great burden on beryllium propellant development. Industrial hygiene techniques and application of micrometeorology can make it feasible to develop and test beryllium-containing propellants.

Light element hydrides also may produce toxic exposure. Lithium hydride powder can produce severe upper respiratory and pulmonary reactions through the chemical reaction which occurs

when lithium hydride comes in contact with moist surfaces. Under these conditions considerable heat is liberated and lithium hydroxide is formed. This latter material has a very strong caustic action. The MAC for lithium hydride is 0.01 mg/m^3.

The higher mollecular-weight boranes retain the characteristic central nervous system effects of other boranes. The primary site of action appears to be upon the central nervous system. Symptom-producing exposures may occur at levels below olfactory detection. It appears from clinical observation that the boranes may accumulate slowly in the body until the body burden is sufficient to produce the signs of the acute disease. These materials are absorbed through the skin as well as by inhalation, and, in the absence of satisfactory air sampling techniques, control of the work exposure is one of great difficulty.

Oxidizers are primarily perchlorates and nitrates. Ammonium perchlorate has been the workhorse oxidizer of the industry for a number of years. To my knowledge, no serious problem has been encountered in the handling of ammonium perchlorate, and there is very little data on its toxicity. Sodium azide has been used as an oxidizer in some propellant operations. Here, again, we have a material difficult to handle in the pure state. It is absorbed into the body through all possible routes and is capable of producing severe depression of the blood pressure. It is almost the rule rather than the exception that when any new operation involving the handling of sodium azide is started medical departments receive a rash of complaints from the workers ranging from mild headaches to generalized collapse. Even with well designed operating procedures established beforehand, headaches are common complaints for the first few weeks. As workers learn the need for geat caution in personal hygiene and material handling, symptoms disappear and problems do not recur until a new worker engages in the activity.

Additives to solid propellant systems run the gamut from materials such as lecithin, the naturally occurring substance in the human nervous system, to copper chromate and lead powder. Most of these materials are added in relatively small amounts. We have noted difficulty in the handling of lead powder used in particle sizes below five microns. Careful industrial hygiene, design, and clinical and medical supervision of these workers has eliminated lead poisoning.

Materials such as lead, beryllium oxide, lithium hydroxide, lithium chloride, boron hexafluoride, oxides of nitrogen, carbon monoxide, hydrofluoric acid, hydrogen sulfide, boron trichloride, all have relatively high toxicities. However, under usual handling operations, these materials are present in significant concentrations

for only short periods of time and have cuased no real problem. Certainly, as the larger booster systems become available, calculations of atmospheric diffusion and wind drift must be made, and with knowledge of the levels of acute effects, testing procedures must be established in such a way that populations around test and operational sites do not receive exposures at toxic levels. Considerable knowledge is available on the toxic effects of materials found in rocket exhausts. This knowledge, though, is based upon exposure conditions of hours or days rather than on the short acute exposure conditions which would occur during the passage of propellant exhaust clouds. In order that proper planning can be made for community protection, further data is needed on short-term acute exposure in the same fashion that similar work is being done presently for liquid propellant operations.

Toxicology handling information should be developed for each propellant system plus table of distances for launch and recorded by a group such as the Propellant Information Agency in the Propellant Manual (SPIA/M2).

Col. Hamilton: Thank you very much Dr. Culver. Our next speaker is Dr. W. G. McKenna, Bureau of Explosives, Association of American Railroads.

Dr. McKenna: The Bureau of Explosives established in 1907 is a contraction of the full name of the Bureau for the Safe Transportation of Explosives and Other Dangerous Articles and it is emphasized that the functions of the Bureau are limited to transportation.

This is not a government body. Actually it is a Bureau of the Association of American Railroads and is supported not only by the Carriers but also by the Shippers of Dangerous Goods. While a majority of the shippers subscribe to membership with the Bureau, non-members may and do utilize the services that the Bureau provides.

The Act of Congress that requires the ICC to formulate regulations for the safe transportation of explosives and other dangerous articles authorizes the ICC to use the services of the Bureau to assist in the formulation of regulations that will result in the best known practical means for realizing safety in transit. This is accomplished initially by investigations of the inherent nature and characteristics of individual articles to determine whether or not the particular article is subject to classification under the Commission's Regulations. If so, into which of the several genetic groups the article falls as a dangerous article of commerce. These genetic groups are specified by name in the Act of Congress and are there defined in the Commission's Regulations.

Once the proper grouping has been determined, it is essential then to consider the balance of the statutory requirements relating to the packaging, compatibility, placarding, marking, labeling, loading and handling while in transit. Also to determine the precautions necessary to assure that the material, when offered to the carriers is in proper condition to transport. This is necessary in order to make effective regulations that will assure practical, reasonable safety in transportation by the particular make or means to be used and to exclude products from regulation that do not afford a regulatory transportation hazard. All of these matters entail considerable study by the Bureau and discussions with the shippers, consumers, container manufacturers, and the carriers.

Based on these investigations, proposals are formulated and presented to the ICC who usually publishes these proposals in a docket for public distribution and for comments or objections from interested parties. The Commission deals with these comments or objections as provided by law before incorporating the proposals into regulation. It is unusual, indeed, for serious objections to be filed after the docket gets to the Commission, since the Bureau attempts to reconcile or resolve differences that occur before the proposals are presented. As a general practice, a docket of changes in the Commission's regulations is made about four times a year.

The point of emphasis here is that the Commission's regulations are flexible within reason and there is a continual mechanism to keep the regulations in step with changes and advances in industrial and military practices.

Once the proposals are adopted by the Commission they are published in the Federal Register. The Bureau then incorporates these changes in a tariff which is published and is available. The effect of this is that all Commission Regulations are assembled and published in one document for the use of all concerned with the handling of regulated articles. Also it eliminates the necessity of each carrier publishing a separate tariff which was the practice many years ago before the present system was adopted.

Section 73.86 of the Commission's Regulations affords means for dealing with samples of explosives and explosive devices. This section states (in effect) that new explosives and devices and explosive products of new factories (exclusive of Army, Navy and Air Force explosives or chemical ammunition of a security classification) must be examined and approved by the Bureau of Explosives as safe for transportation before being offered for shipment except for the specifically defined samples.

This section outlines the condition for legal shipments of samples for laboratory examination.

Section 73[51] excludes those explosives that are unsafe for shipment under any conditions - or - to use the nomenclature in the Commission's Regulations - the so-called Forbidden Explosives. "For the purpose of the Regulations a new explosive, including fireworks and explosive devices, is the product of a new factory or an explosive or explosive device of an essentially new composition or character made by any factory."

The Explosive Category is one of several general groups of dangerous articles specified by class names in the Act of Congress and defined as to limitations in the ICC Regulations. The other general groups include Flammable Liquids, Corrosive Liquids, Flammable Solids, Oxidizing Materials, Compressed Gases, Poisons, etc., all of which may be sub-divided by definition or explanation into smaller more specific groupings of the general classes.

The ICC Regulations Section 73[50] defines an Explosive for purposes of transportation as "any chemical compound, mixture or device, the primary or common purpose of which is to function by explosion (that is) with substantially instantaneous release of gas and heat" - unless such compound, mixture or device is otherwise specifically classified under the ICC Regulations.

This defines explosives, in general, as considered in the Regulations and this general class of acceptable explosives is then sub-divided into three sub-groups as Class A, Class B and Class C with additionally the so-called Forbidden Explosives specified.

The Class A Explosives are those that - in general - essentially function by - or - more specifically present a primary hazard of mass explosion or detonation under conditions incident to transportation. There are nine specified and defined sectional types or groups of the Class A explosives and specific tests to determine the peculiar characteristics and to pin-point the particular sample more specifically are outlined in detail in the ICC Regulations.

The Class B Explosives are those that - in general - function by or present a transportation hazard of rapid combustion rather than detonation.

The Class C Explosives are defined as "certain types of manufactured articles which contain Class A or Class B Explosives or both as components but in restricted quantities. This class

includes many manufactured articles such as small arms ammunition, some fuzes, squibs, igniters, and certain types of fireworks, etc.

The practice has been to list by name and description all the specific devices in the Class C group but this list recently has been increasing steadily and means for dealing with these devices by more general groupings are now being considered.

The Propellant Explosives both liquid and solid - to date - in general fall into the Class B classification since by nature and performance characteristics, the Class B Explosives are those "that function by rapid combustion rather than detonation..." However, this is not entirely the rule for ICC classification. If authorized or required tests show that any sample regardless of end use or mechanism of performance, may present a hazard of detonation in transportation, such sample would fall, legally, into the Class A group and would be so classified for shipment. Some few propellants may perform in tests in a manner to indicate that more adequate transportation safety might be realized by the Oxidizing Material or Flammable Solid Classifications but these cases are not common or usual.

The exact or specific status of all new explosives under ICC Regulations must be determined by tests. These tests when performed at the Bureau Laboratory in South Amboy are carried out after discussion or correspondence. It is of utmost importance that some information as to the general composition or the handling and manufacturing experience be furnished in order to indicate reasonably the probable behavior of the sample in tests. This is essentially for the protection of the investigating staff in handling these new materials.

There are four general or basic tests to which all samples of explosives are subjected. These tests, not necessarily in order of procedure and not necessarily in similar details of procedure are:

<u>1st Test</u> - A portion of the sample is placed in a suitable vessel and maintained at 75°C for 48 hours. This test is usually conducted in a suitable well barricaded incubator oven. The stability of the test sample is determined by observation, weighing or chemical tests as well as the obvious one as to whether or not an explosion or vigorous decomposition has occurred during incubation. Under some circumstances the test might be carried out in stages starting with very small quantities and progressively increasing these quantities until sufficient informative test data are obtained.

2nd Test - Portions of the sample alone and (if a liquid) sterile absorbent cotton saturated with the liquid sample are subjected to initiation by a #8 blasting cap. This test is conducted with the test portion or vessel set upright on a cylindrical lead block which in turn, is set on a piece of steel plate. In each case the blasting cap is set in contact with and perpendicular to the test sample at the approximate center of the exposed upper surface. The test is, obviously, conducted behind a barricade. Any deformation of the lead block is an indication of detonation. The noise, flame, scattering of the sample or the test vessel are noted for comparative purposes.

3rd Test - A portion of the solid sample or in case of a liquid - a train of wood sawdust wetted with the liquid is ignited remotely by a squib or flare. The burning characteristics of the unconfined sample - whether slow or rapid - explosive or detonation are observed and noted.

4th Test - Small portions of the sample alone - or if a liquid - additionally small circles of filter paper wetted with the liquid are subjected to 3 3/4 and 10" drops in the Bureau of Explosives impact apparatus. The behavior of the sample is observed by the noise, flame, action of the striking piston - or in case of a liquid - by the shape of the small copper containing cup - of which a new one is used for each test. Prints of the apparatus and details of procedure are available.

These are the general tests for explosive classification under ICC Regulations. They are not necessarily entirely final. In the event that the sample may have some unusual or peculiar characteristics such as extreme flammability, be unusually corrosive, toxic, reactive with moisture or air, etc., to the extent that such characteristics could be a significant factor in transportation safety - additional tests will be conducted and these results considered in the recommendation for ICC classification. In some very unusual cases, tests may indicate that the sample is now adequately classified as an oxidizing material or flammable solid. In case of propellants, a defined fire test may be used.

Based on these test results, a recommendation of ICC classification will be made. If the test results indicate the sample to have conventional characteristics that are recognized by experience, conventional methods of packaging will be authorized. If the results show the sample to be unusual or peculiar, additional recommendations as to more restrictive packaging and handling may be made in order to effect a reasonable degree of safety in transit. If it is desirable or advisable, discussion of test results with the shipper will be welcomed.

The Bureau maintains a staff of trained field representatives situated at various points throughout the continent. The services of these men is available to you on request. The Bureau of Explosives man in your district is a good man to know.

Mr. P. H. Strietzel, Aerojet-General Corp.: What you have given in your discourse Dr. McKenna is general requirements, however, I find a number of problems of detail to actually prepare the propellant samples and get them to you. So I have quite a number of questions that I would like to ask regarding that. No. 1, can propellant samples larger than 1/2 pound be shipped to you, can they be shipped by freight, or only by rail express and can more than one identity be shipped in one container?

Dr. McKenna: You have asked me several questions in one. The answer to the first I think is that the Commission's Regulations provide for shipments of units up to 5 pounds. By Express I think it is limited to half pound samples. As to whether or not more than one can be shipped in one container, the regulations do not prohibit more than one in a container except for the general provision that compounds of materials that are not compatible must not be packaged in the same container. My own suggestion is that you do not ship more than one sample of a new explosive in one individual container. For one thing, it will simplify our handling at South Amboy.

Mr. Strietzel: In regard to that, isn't it difficult for you to receive at the laboratory at South Amboy anything that is not shipped to you by rail express?

Dr. McKenna: Since the explosion in South Amboy about ten years ago, there has been up til now a local ordnance prohibiting the acceptance by the railroad of explosives for shipment into South Amboy by freight. However, we do have a provision in that ordnance with the city officials that we can receive samples by express and we prefer that you ship them by express. If you shipped them by freight, it is necessary to go to New Brunswick or Trenton and pick them up. Incidentally in New Jersey, there has just been passed an act in which all these local ordnances are subordinated now to one code or ordnance of the state. The State people tell me, these local ordnances have no point. I don't know just where we stand. I was assured by the state labor man that there wouldn't be any interference with our activities. In answer to your question, I would prefer you to ship them by Express.

Mr. Strietzel: ICC Regulation 73.86 says that "samples of new explosives other than those of a security classification for Army, Navy and Air Force shall be shipped to" you. Where can

those of a security classification be shipped? And if the identity of a propellant formulation is concealed by a code number, can it also be shipped to you?

Dr. McKenna: To answer the last part of your question first, certainly if it's identified by code number. Most of our samples that we get now are identified by code number and they are so shipped legally. Where samples of a security classification can be shipped I think is beyond me. I presume they can be shipped to installations that have proper clearance. I understood that we have that down in South Amboy.

Mr. Strietzel: Up to this time I have not learned of any other location in the military services where samples would be tested in a manner similar to that you perform at the Bureau of Explosives laboratory.

Dr. McKenna: I don't know of any either. I can't give you any specific answer to it. I don't know of any other laboratory on the continent that's doing the same type of work that we are.

Mr. Strietzel: In Regulation 72.51 "forbids shipment of unsafe explosives." Does this mean that samples can not be shipped to you until the shipper performs tests to determine they are safe and what must be learned from these tests, what equipment is required. Can local Bureau of Explosives inspectors advise the shipper how to determine whether any kind of new explosive is prohibited. In other words, it looks like the shipper must determine by test that the material is safe to ship before we can even ship samples to you, and we can't do any shipping of larger quantities until such samples are classified according to ICC Regulations.

Dr. McKenna: I think the answer to your whole question is yes, you should perform certain tests and there are certain conditions that are outlined in the regulations. Besides that, I think you should use some judgment as to what you're shipping to us. The answer as to whether the Bureau of Explosives inspector can assist in these tests or observe them, I think is yes. I think it would be a good idea to have him do it.

Mr. Streitzel: What unit container enclosure do you recommend for desensitized granular explosives such as hydrazine perchlorate material, since such material may leak into the threads of a screw cap closure and dry out and detonate when the cover is removed?

Dr. McKenna: Well, I certainly don't recommend any kind of a glass closure with a rigid threaded cap where there may be some segregation of the dry explosive. I think the best container is a rubber one with a rubber stopper secured by copper wire or something like that. I'm not too happy with these plastic containers. I've never had any trouble with them, but one hears so much talk about static with them.

Mr. Strietzel: When fine samples of propellant are ICC Class B, can large grains of this propellant then be offered for shipment Class B when confined in shipping containers or rocket motors?

Dr. McKenna: I think you have to split that question in two. I think certainly these large grains can be shipped in ICC approved containers but when they're put in a rocket motor, conditions are changed altogether, so the classification then subordinates the classification of the propellant in itself to the classification of the unit as an assembly. There are further considerations of the unit, whether it has an igniter, what type of an igniter, how much confinement there is, what possible venting areas there are, etc. Very often we would want a fire test. Those fire tests now are required less frequently than we did awhile ago because we're gaining experience now so we can make intelligent estimation.

Mr. Strietzel: There is a section in the regulations that requires in addition to the tests on the unconfined samples, in other words, we send unconfined half pound samples to you and you classify them as Class B, that in addition to this, that when these samples or larger quantities are confined in a shipping container, that shipping containers with this material in them must be stacked and tested by fire to determine whether their confinement in the shipping condition will cause them to detonate and raise the classification to a Class A. Is this additional test required when we ship propellant quantities after we have shipped our samples to you and had them classified?

Dr. McKenna: Well, I think it could be required. Actually the reverse of that is being used. I just did some tests for the Canadian Government on some explosive that by these so-called conventional tests where we came up with a Class A classification and the fire test, much to my surprise, didn't result in a detonation so the shipper got this classification reduced to Class B. It meant a lot of money to them.

Mr. Levens: I refer again sir to Section 73.86 which for new materials is the one most of concern. Two questions, one at a time. The first is related to the distinction in this section between the shipment of five pounds in one outside container by freight, but also the provision that 1/2 pound inner containers may be

shipped by rail express with up to 20 such samples in one outside container. Can you discuss the rationale between them?

Dr. McKenna: No, on the surface of it it looks irrational, but it isn't really. In answer to Mr. Strietzel's question a minute ago, I suppose legally more than one sample could be shipped in one container, but it just isn't a good idea. The regulations are a little hazy there I think.

Mr. Levens: I referred there specifically to the same material, but broken up into small lots simply for the purposes of complying with the rail express requirements.

Dr. McKenna: Let me answer it this way. We get them in that way.

Mr. Levens: Of course I recognize that much of this problem would be solved by communication with you prior to shipment but this is a question which arises frequently in the laboratory and one has to have a satisfactory answer. The second question I have relates to the shipment of new explosives for laboratory examination. Here we have the problem that we have taken the position that a new material must be shipped to the Bureau for examination first. But we are under considerable pressure by the laboratory people who would like to send such new materials to other laboratories for examination prior to examination by the Bureau. What do you have to say about that situation?

Dr. McKenna: The regulations legalize that. That regulation was not limited to shipping the samples to the Bureau of Explosives laboratory. That regulation legalizes and authorizes shipment of samples for laboratory examination, and it doesn't say which laboratory.

Mr. Levens: In other words, to clarify this in my own mind, if one has a new explosive which has not been examined by the Bureau that provided the shipper is satisfied that it fulfills the requirements of the basic tests you have outlined, such sample may be shipped to another laboratory for examination.

Dr. McKenna: Of course in your second question now, you introduce a new word, you said new explosive. I would say that as long as you complied with the requirements of Section 73.86 that you could ship from one laboratory to another as long as it's only for a laboratory examination. As a matter of fact we're working that out with Mr. Herman's group and if my memory serves me correctly, we're clarifying that in his report that he proposes to distribute here as soon as it is completed.

Mr. Jezek: When Mr. Harry Campbell was in charge of this outfit up in New York, I discussed this business of new explosives with him and he said that if you have a rocket propellant and all you're doing is changing one ingredient in the composition, to him that was not a new explosive, it was still a rocket propellant. But if you come up with some brand new item that nobody ever heard of and doesn't know a thing about it, in his opinion that would be a new explosive. Now maybe Mr. George differs with Mr. Campbell, but so far we haven't been lead to believe differently.

Dr. McKenna: I think the regulations are pretty specific about that. It says for the purposes of these regulations "new explosives including fireworks and explosive devices that are a product of a new factory or an explosive or explosive devices of an essentially new composition." Our interpretation of this is that a minor formulation change in an already approved explosive does not require a second approval so long as the change does not affect the explosive characteristics. The original formulation should be approved and if a significant change in formulation is made, the explosive should be re-examined.

Mr. Roylance: There is a provision in the regulations I think where contractors to the military departments can get an interim classification from the head of that department, the Chief of the Bureau of Naval Weapons or the Chief of Ordnance, for shipping materials for test purposes prior to get a Bureau of Explosives classification on the item. I think this probably answers the problem in these particular cases. In other words, the services can classify.

Dr. McKenna: The regulations authorize that. I don't know where this is done, but the law permits this.

Mr. Zampatti: If you don't mind, I'd like to bring you up-to-date on some of these questions that have been asked before in this area. I'd like to get some specific information if I can with respect to the questions that Mr. Strietzel from Aerojet-General asked and I'm primarily concerned with the GAM 87 system. For everyone's information, the propellant samples to my knowledge have been classed and were reviewed by the Bureau of Explosives as being a Class B type propellant, however, as I understand it, Air Force designation has been established as Class A type of weapon or motor because of the fact we're talking about confined propellant whereas the samples themselves were unconfined in the testing. The thing that I'm concerned with is this. What we have to do in order to establish a Class A designation, you mentioned a conflagration to burning type test, could you be more specific in this area. That would be question no. 1. In other words,

here we're stuck with a Class A designation, let's say our Air Force technical advisors have recommended this, what further testing do we have to do right now in order to establish Class B designation and no. 2, I'd like to find out also what have other services or weapons systems managers done for their systems. Have they had to wait until full-scale motor tests were conducted before they establish an interim or fully official classification for their particular systems?

Dr. McKenna: Well, I think the answer to a good deal of the question you ask there is an internal matter of the services of which the Bureau wouldn't have any knowledge officially. I don't know what the requirements of the Air Force or any other services would make to classify a motor.

Mr. Ackerman: In order to determine the classification of any item you have the Air Force Technical Order 11-A-1-47 to comply with. In addition to that, and additional tests that are necessary will be determined by the developmental activity responsible for development of that item. Under the letters that were submitted from our headquarters to the developmental activities within our command, you were directed to submit any questions in connection with minimum test criteria to the Command. To date, we have not received any from the GAM-87. We'd like to know what your problems are, we'd like to help you.

Col. Hamilton: I think that this is something internal to the Air Force and we shouldn't take up time at this conference.

Mr. F. N. Olsen, Boeing Co.: Are you aware of any revisions to ICC regulations to include private carriers of explosives under the same regulations as applies to the public carriers?

Dr. McKenna: In the first place, the answer to your question is yes and I think Mr. Haninger sitting down here would be an excellent person to answer that question. As I understand, the ICC has just less than a year ago, assumed jurisdiction over private carriers. I would certainly welcome Mr. Haninger's answer.

Mr. V. E. Haninger, ICC: Do you have any specific carrier in mind or method?

Mr. Olsen: I was speaking of the Roseburg incident and the ruling that the Federal Court handed down in that incident.

Dr. McKenna: The answer to your question is that the change was made after the Roseburg incident. Whether or not the Roseburg incident had anything to do with it I don't know.

Mr. G. Pexton, Munitions Carriers Conference, American Trucking Assoc.: I just wanted to add to Dr. McKenna's comments, I wasn't here yesterday, that we subscribe thoroughly in the American Trucking Assoc., Munitions Carriers Conference, to all these items of safety. We further would request all of you manufacturers and you people who deal with these items to give us a little advance knowledge as possible of what you're doing. We are fully familiar with the fact that state and local regulations and ICC regulations are not very good, frankly. They conflict constantly, we're fighting them day in and day out. The Bureau of Explosives in connection with the Munitions Carriers Conference is working on that with me. We're meeting on an explosives advisory committee. The big thing that we would like to point out, going along with Dr. McKenna, is information. The Roseburg incident just as well as the McCloud incident up north a few weeks back, were not by carriers party to the Munitions Carriers Conference or regulated by a regulatory body such as the Commission. In fact, they were an authorized carrier, on the other hand, I think these incidents can be avoided with proper safety practices and speaking for the Munitions Carriers Conference, I'd be very happy to assist you gentlemen in any way at any time.

Mr. Jezek: We're having an awful lot of trouble calling a rocket motor a rocket motor because the ICC Regulations have no provision for calling a rocket motor a rocket motor. Is anything being done in your office to include the nomenclature of rocket motor Class A or rocket motor Class B?

Dr. McKenna: I haven't heard of that designation. I have the latest docket here with me that has been presented to the Commission and I don't know of it. Certainly if you want that designation in, a request will get it in. If it is essentially different, all you need to do is make a request to our office and we'll take that up with Mr. Haninger as a suggested new item. There would be no difficulty whatever in having it done.

Col. Hamilton: Thank you very much Dr. McKenna. Mr. Fernandes of the Bureau of Naval Weapons is ill and will be unable to make his presentation. Yesterday we missed hearing from Dr. Ball of Hercules Powder. Dr. Ball is going to tell us about an unfortunate incident they had at the Allegany Ballistics Laboratory on the 22nd of May of this year.

Dr. Ball: On 22 May 1961 an explosion occurred at Allegany Ballistics Laboratory resulting in 9 deaths, 4 injuries requiring hospitalization and 44 minor injuries. Together with an ensuing fire, this event caused roughly one million dollars property damage.

The chronology of events is shown in Table I.

The explosion took place at Building 105A, the casting building of the pilot production line, which was completely demolished. Flaming brands from the explosion set fire to two rest house and conditioning houses situated behind a barricade. Building 74 contained bare grains and loaded rocket motors in the rest house bay. Building 73 contained bare grains and loaded rocket motors all inside conditioning ovens. The fire in Building 74 spread to the contents in about half an hour, while the fire in Building 73 burned for four and a half hours before any of the contents ignited. After an additional two hours, a "non-propulsive" unit emerged, which hit and set fire to a third conditioning house, Building 86, also containing loaded rocket motors. Burning contents of this house set fire to the barricade at Building 109. The fires at Buildings 73, 74 and 86 were not fought because of their contents. When it was ascertained that no fire was present on Building 109 itself, the barricade fire was extinguished.

TABLE I

CHRONOLOGY

Explosion, Bldg 105A	0850
Fire, Structure Bldgs 74, 73	"
Fire, Contents Bldg 74	0920
Fire, Contents Bldg 73	1400
Propulsive unit from Bldg 73, ignited Bldg 86	1555
Fire, Contents Bldg 86, ignited barricade 109; fire fought	1605
Fires out	1730

The area concerned is shown before the explosion in Figure 1, and after in Figure 2.

The relationships between the various buildings is shown to scale in the map, Figure 3.

Building 105A was a multiple function concrete structure in which molds were filled with casting powder in either of two bays, the loaded molds were evacuated for a period of several hours in a third bay, and casting solvents were adjusted for composition and the casting operation was performed in the fourth bay. During the weekend before the explosion, a considerable quantity and variety of experimental casting solvents, including some 99% nitroglycerine, had been moved into the solvent bay for temporary storage. This movement had been made under direct control of an area supervisor and was accomplished without incident.

On the day of the explosion, the experimental line was ready to resume normal operations. Two trucks, each manned by two powder service operators, had been sent to Building 105A to retrieve the experimental solvents and an operator from the experimental area was present to advise and assist them.

Figure 1

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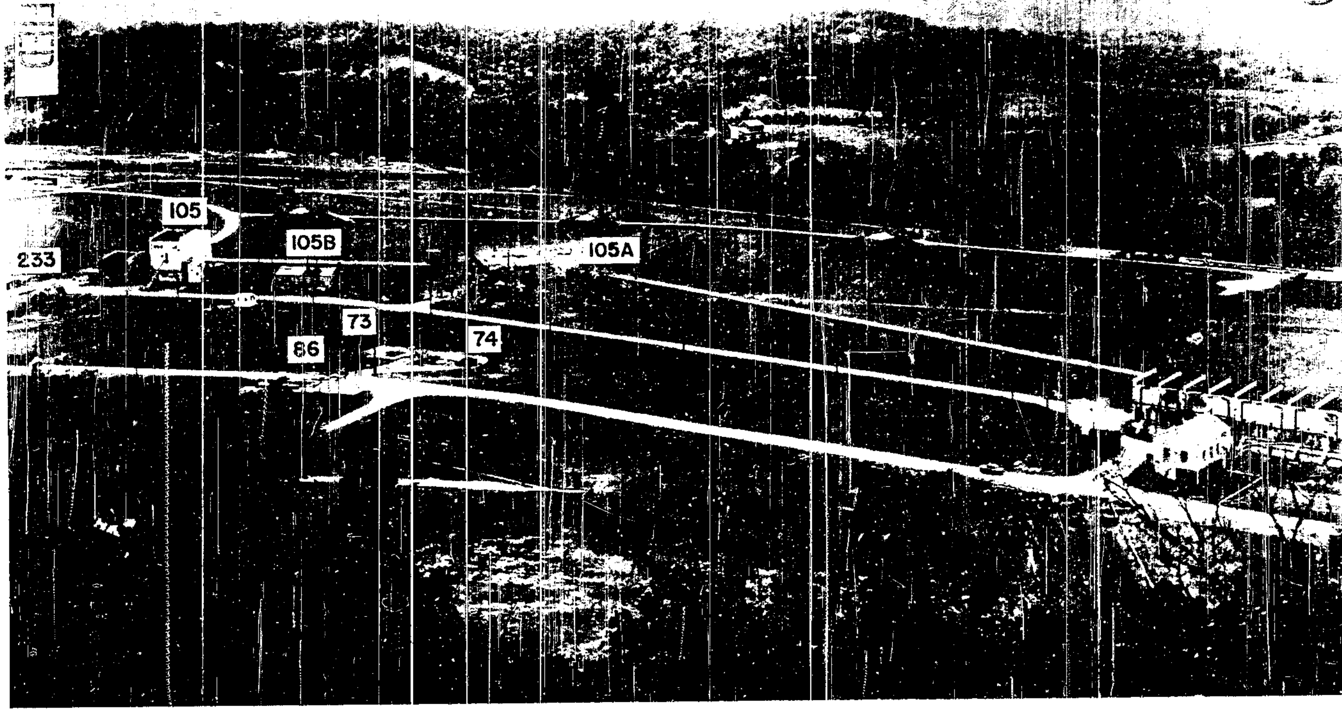
Figure 2



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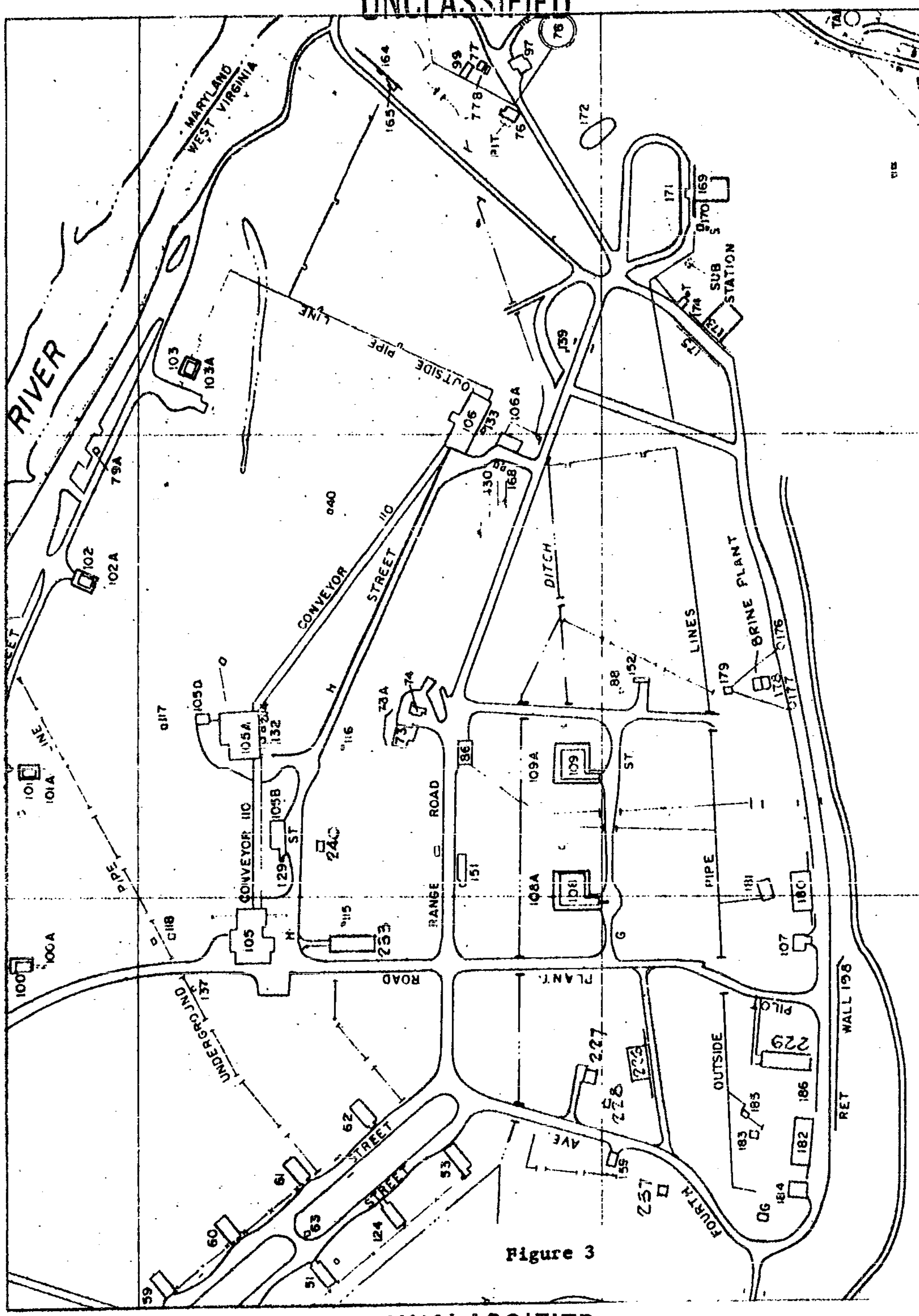

Figure 3

UNCLASSIFIED

A powder service area supervisor was en route to check this loading of the solvent containers on to the trucks and was within 50 feet of the building when it shot. No pilot line operations were under way, nor were pilot line personnel in Building 105A. Four maintenance men were in the immediate vicinity, three making adjustments on the overhead monorail system connecting Buildings 105A and 106 and one about to leave after having checked air conditioning equipment in the attached utility building. The arrangement and contents of Building 105A at the start of the day are shown in Figure 4.

A number of the 37 visiting containers of solvent are known to have been loaded on to one of the trucks. These containers were of 4 types varying from 10-quart hand carried ICC standard nitroglycerine cans to pallet-mounted desiccators of about 50-gallon capacity.

The direct cause of the explosion will never be known with certainty. The most probable cause is a handling accident on the partially loaded truck, or between the truck and the MI area of Figure 4. The sensitivity and brisance of the 99% nitroglycerine are sufficient to enable prediction of propagation of detonation to all of the casting solvent in the building and in the truck, provided that any one container of solvent was initiated. The further prediction can be made that the 12-inch concrete wall would fail

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SKETCH OF INTERIOR OF BUILDING 105 A
SHOWING LOCATION OF EXPLOSIVES

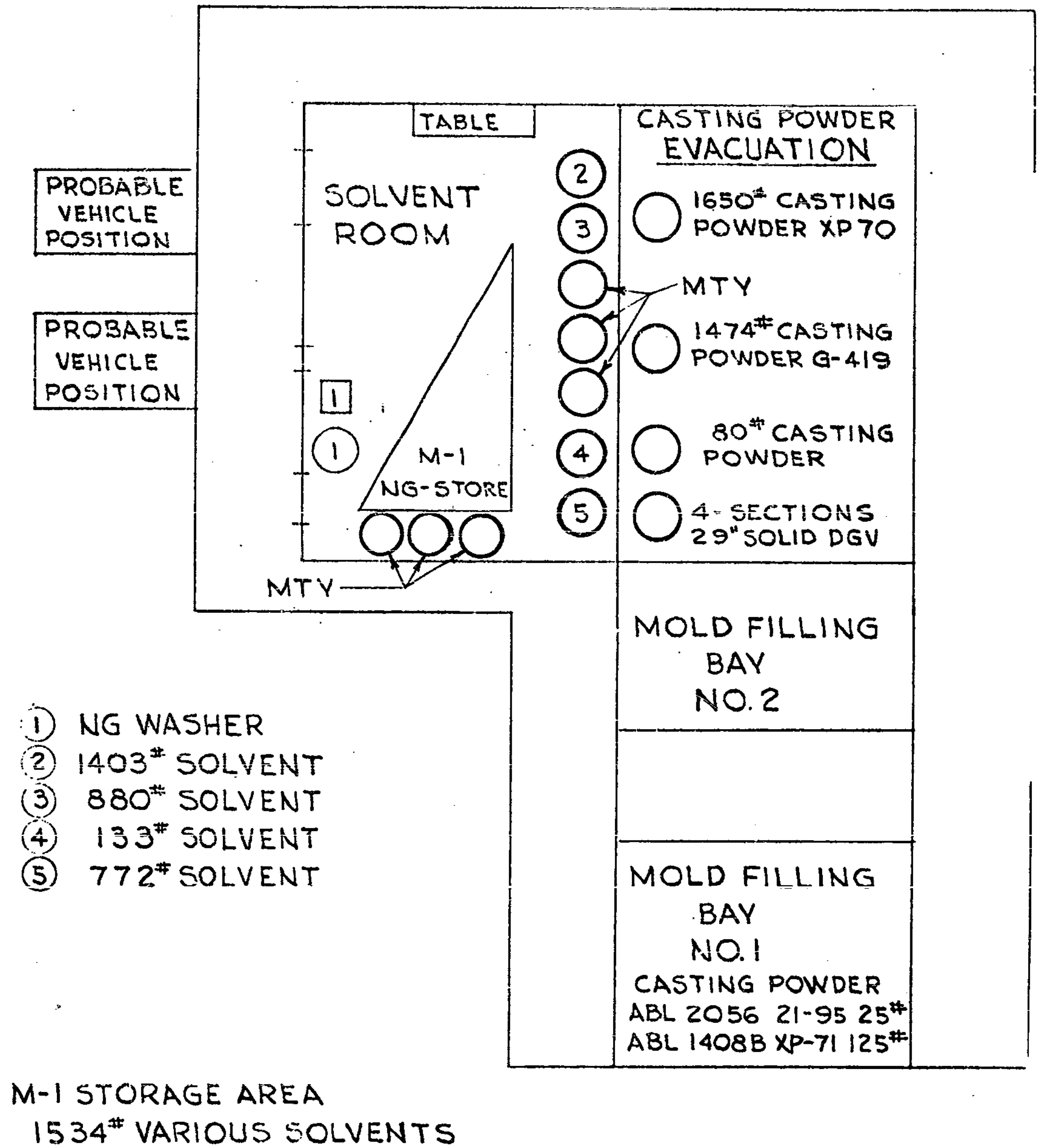


Figure 4

UNCLASSIFIED

and debris would ignite the casting powder in the molds. The casting powder would or would not burn to detonation depending on the size of vent produced in the mold by the entering debris. An intact mandrel from one of the molds indicates that casting powder in one mold failed to detonate. It is therefore necessary only to explain initiation of the first container. The explanation is easier if the assumption can be made that a spill of one of the more sensitive solvents occurred, followed by impact or friction in the spill region between any metals such as a pallet truck wheel and the dock plate, or between the concrete dock surface, and a metal object. A spill could occur if a 10-quart can were dropped or presumably if a desiccator were upset by mishandling. It is not absolutely necessary to assume a spill, as dropping the 10-quart container of NG on steel or concrete would have a reasonable probability of resulting in detonation.

In routine manufacturing operations, standard operating procedures exist and are followed. These SOP's reflect a careful study of existing hazards and incidentally give a clearer picture of what was going on at the time of a mishap. This particular solvent handling operation was not a routine manufacturing operation. In the absence of a SOP, reliance was placed on general operating procedures and on direct control of an area supervisor. The movement into Building 105A had been successfully made in this manner. The advisability is suggested of writing and following SOP's for nonroutine operations involving explosive systems.

The total amount of detonable explosive at the site was about 8,000 lb. At least 6,500 pounds of this is presumed to have detonated. From the chart "Peak Blast Pressure as a Function of Distance and Weight of Explosive" (ASESB 1 Nov. 1960) the side-on peak blast pressures at several distances from the center of an 8,000 lb. blast and from the center of a 6,500 lb. blast have been tabulated as shown in Table II.

Personal injuries have been analyzed in the light of these peak pressures. The results are shown in Table III.

The five operators who were moving solvent were dismembered. Positive identification was established primarily through the efforts of the FBI Disaster Squad whose services were made available through the courtesy of Mr. J. Edgar Hoover. This assistance is gratefully acknowledged.

The four maintenance men at the site were also killed instantly, but left intact. In the absence of autopsies, their fatal injuries are presumed due to blast, though some missile damage to the bodies was also apparent.

The pickup approaching Building 105A was showered with missiles, the windshield shattered, and the fore part of the roof, particularly on the right side, caved in and cracked by falling I-beams from the overhead monorail. The vehicle, which had just stopped, was driven back some fifty feet by the force of the blast. The passenger, his head pinned between the back of the cab

TABLE II

DISTANCE vs PEAK OVERPRESSURE

Pressure	Distance 8000 lb	Distance 6500 lb
100	68	63
50	85	80
30	102	97
20	120	112
10	160	150
5	230	212
2	420	400
1	780	730
0.5	1500	1850
0.1	7800	9600

TABLE III

DISTANCE vs PERSONAL INJURY

Location	Distance	Peak Press	Total Exposed	Fatality	Hosp.	Minor	Uninjured
Bld 105B	<50	>200	9	9	-	-	-
Pickup	60-100	100-30	2	-	1	1	-
Bldg 105	350-450	2	27	-	1	11	15
Bldg 233	450	<2	5	-	-	3	2
Bldg 86	500	<2	1	-	1	-	-
Station Wagon	500	<2	3	-	-	3	-
Misc.	>800	<1		-	-	26	
Bldg 226	1000	<1		-	1	-	

and the wreckage of the roof, was hospitalized with head lacerations. The driver, also cut about the head, was a first aid case. He suffered, in addition, a temporary impairment to his hearing that persisted about ten days.

The men in Building 105 were completely shielded from low trajectory missiles. The one man hospitalized was working on a space heater on the outer wall of the building and standing on a steep ramp three or four feet from the ground. His injuries were a fractured scapula, lacerations, contusions and shock, all incurred when he fell or was thrown from the ramp and hit a wooden post. The minor injuries from this area were shock and contusions, with one case each of temporary loss of hearing and muscle strain.

Five men were applying insulation to the interior of the quonset, Building 233. The blast dislodged all of the wet insulation, covering the men as well as the floor. Three of this crew received first aid treatment for contusions and lacerations; the other two were uninjured.

The man hospitalized from the Building 86 area was the most seriously injured survivor. He had just finished checking the contents of the ovens and had started to walk toward his parked car. In that location, the barricade at Buildings 73 and 74 was between him and Building 105A. He was facing generally toward the blast and was struck on the left side by a missile, not identified, which

was at a considerable angle to the direct line. His injuries were described as "rupture of abdominal wall; resection of intestines (3 ft.)." As of this writing (mid July) the man is recovering, but he has not regained the full use of his legs.

Three men were driving through this immediate area in a station wagon at the time of the shot. All received minor injuries.

A man in the open field behind this building was uninjured.

The fourth hospital case was about 1,000 feet from the blast. He had been stripping forms from new concrete at the top of Building 226, was struck by a missile and suffered a compound fracture of the scapula from the missile and/or his descent.

The remaining minor injuries were a mixture of contusions, shock, lacerations, muscle strain and temporary loss of hearing, primarily due to psychological reactions to the noise of the explosion.

Only one of the four hospitalizations is directly traceable to low trajectory missiles. Barricades at the source might have prevented this injury by stopping the missile. Most of the minor injuries, however, were not due to missiles.

The comparatively low incidence of personal injuries indicates that the intraplant table of distances is conservative for a shot of this magnitude, particularly for people within structures that stop incoming missiles.

In a similar manner, property damage can be looked at as a function of distance or overpressure, as outlined in Table IV.

TABLE IV - DISTANCE vs PROPERTY DAMAGE

A = total loss, B = major structural damage, C = substantial damage, D = minor structural damage, E = incidental damage, F = no damage, (b) = barricaded

Building	Distance	Peak Pressure	Construction	Damage
105A, D	0	200	concrete	A. Demolished
105B	200	7	block	C. Roof, block walls
240	250	4.2	frame	C. Roof, one wall, equipment
73	325(b)	2.7	frame	A. Burned
74	360(b)	2.4	frame	A. Burned
105	375	2.2	concrete	C. Roof, partitions, sprinklers, equipment
233	450	1.8	quonset	C. Frame bent, siding
101	450(b)	1.8	frame	D. Roof
102	450(b)	1.8	frame	E. Doors
86	475	1.7	frame	A. Burned
151	525	1.5	block	C. Block structure, equipment
79A	675	1.2	frame	E. Door frame
100	675	1.2	frame	E. Doors
109	700(b)	1.1	block	C. Roof, block wall
106	700	1.1	concrete	D. Doors
108	750(b)	1.0	block	C. Roof, block wall
103	775(b)	1.0	frame	E. Doors
130	775	1.0	steel	F.
168	800	1.0	steel	F.
106A	525	0.9	block	D. Roof, doors
62	825	0.9	frame	E. Door
152	850	0.9	block	C. Block walls
61	925	0.8	frame	E. Door
216	1125	0.7	frame	C. Walls displaced
180	1225	0.6	concrete	D. Escape tunnels
107	1250	0.6	frame	D. Escape tunnels
182	1450	0.5	frame	D. Sprinklers, skylight

Several tentative conclusions can be drawn from the data as tabulated. Aside from the buildings destroyed by the blast or by subsequent fire, no "substantial structural damage" was incurred by buildings beyond Class 9 intraline distance. Two buildings closer than Class 9 intraline distance also survived without substantial structural damage. Damage at Building 105A is shown in Figure 5, and at Building 233 in Figure 6. The table of distances is conservative with respect to structural damage.

In this explosion, and indeed in most plant-site explosions, there were many more target buildings than donor buildings. These ranged in distance from the donor from intraline distance, where peak blast pressure should have been about 3 psi for a full-scale donor and about 2 psi for the actual donor, out to about 1500 feet where the calculated peak blast pressure was about 0.5 psi. All buildings inside the 1.0 psi contour received some blast damage, and none beyond the 0.5 psi contour were hurt. Heavy non structural elements including sprinkler systems, doors, piping and electrical systems, supported by walls and ceilings added substantially to the damage in these lightly shocked buildings. In addition to the blast damage, there was considerable missile damage to roofs. These buildings were all of state-of-the-art construction, designed to withstand the elements and normal wear and tear but with no particular provision for the forces that might be experienced during an explosion.

Figure 5

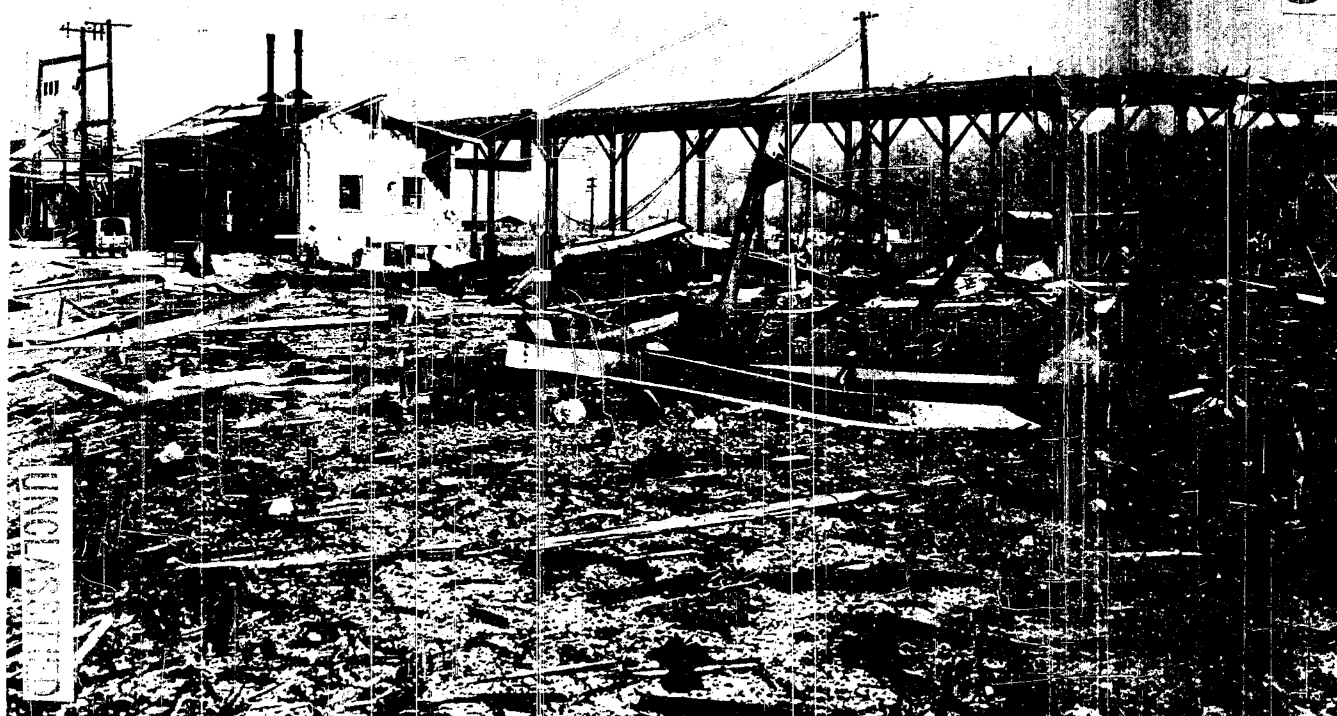


Figure 6

We submit that state-of-the-art may not be quite good enough. The problem of building design for plant sites on which explosives are handled should be approached from the standpoint of providing assurance that target buildings, regardless of whether they house explosives, people or valuable property, should be able to defend themselves in case of an explosion in the plant area. The design requirements and cost for building shells to withstand up to 5 psi blast peak pressure should be determined. This will require the ability to calculate dynamic loads, for which the necessary information is now believed available. Since the building shells will move under blast impact, means should be developed for supporting heavy loads independently of the building shells. Lightweight roofs are good on donor buildings in that they afford quickventing and do not add appreciably to missile distribution. They are bad on target buildings in that they afford inadequate protection from missiles. Since there are more target buildings than donors, serious consideration should be given to hardening roofs and making other provision for venting possible donor buildings.

Damage to Buildings 105 and 109 indicate that target barricades open at the top apparently did not diminish peak blast pressure. This indication does not affect Hercules' confidence in the merits of control bombproofs protected overhead and open only on the lee side.

Buildings 182, 107, 180 and 216 were more extensively damaged than other buildings of similar structure at comparable distances or even nearer. These buildings are all located at the foot of a talus slope. Ground effects and/or blast reflection are suspected of having played a part in causing this damage.

In addition to building damage, one or more fire hydrants were sheared off by missiles, causing the loss of an appreciable part of the plant's water reserve. The fire water distribution system should be modified to be less vulnerable in a future emergency.

The ABL disaster plan was put into effect immediately after the shot and was effective in preventing further injuries and damage. All operations except the pilot line were resumed the following week after thorough check of electrical and sprinkler systems and load testing of all hoisting equipment.

Mr. Perkins: First of all I want to preface my remarks with praise for the detailed investigation and the information supplied. In view of the fact that we had the unfortunate incident, I'm glad that we at least got this kind of accident analysis. I'd just like to put in a word of caution here with respect to the discussion of the peak pressure particularly with regard to the direct effect of the blast on the humans involved. Of course, I'm the last man in this room that should question anything about the detonation going through the wall and I won't but I want to point out that we did have in one of our tests a case where propagation of an explosion through the wall occurred and one of three high explosive charges in the cell through which the propagation occurred did not detonate or even burn. They found pieces of it and I wonder if we haven't perhaps accumulative error here in computing the amount of HE that probably did detonate coupled with a little bit of safety factor on our pressure curve that tends to make us think these people were subjected to greater blast pressure than they were. I wouldn't want to assume from this incident that we could raise the figures that the medical people have given us on the vulnerability of the human body to blast because of the relatively close-in survivors that you have.

Dr. Ball: I must agree that you have a point there. Obviously I can't answer it one way or the other. On the other hand, the structural damage tends to indicate that we did have pretty good blast picture.

Mr. P. V. King, Aberdeen Proving Ground: Dr. Ball, I'd like to know if this was side-on or face-on pressure you calculated?

Dr. Ball: This was all side-on. Actually as far as people were concerned, with the one exception of the man that was hit by a missile. I neglected to mention that this missile was a ricochet and wasn't a direct hit because we traced the course of the missile by the path it made on his body and that was at a considerable angle from a direct line. With the exception of him and the other man I didn't tell you about, the fourth hospitalization case, he was a direct missile hit and he was 1000 feet away from the place. He was stripping forms off new concrete. He was hit by a missile and got a broken shoulder either from the missile or from his descent. He was up on top of a sloping barricade with a concrete structure up top. All the data in this is side-on, if you want to convert to face-on at places where face-on was experienced, you know the factor.

Mr. McQueen: Dr. Ball, did you observe any structural damage to adjacent facilities that you could attribute to ground shock and how would you relate this to future troubles?

Dr. Ball: I'm glad you mentioned that, because that's something else that's in the paper and I didn't mention it. The last four entries on that structural thing were buildings that were at the foot of the slope there. If you've been to Allegany you know that it's largely a flat and then there's a 40" steep slope of loose stones there, these four buildings were right close to it and they were hurt worse than similar buildings closer in. This might have been reflection or it might have been ground shock. At any rate we wouldn't put them there if we had room to put them anywhere else.

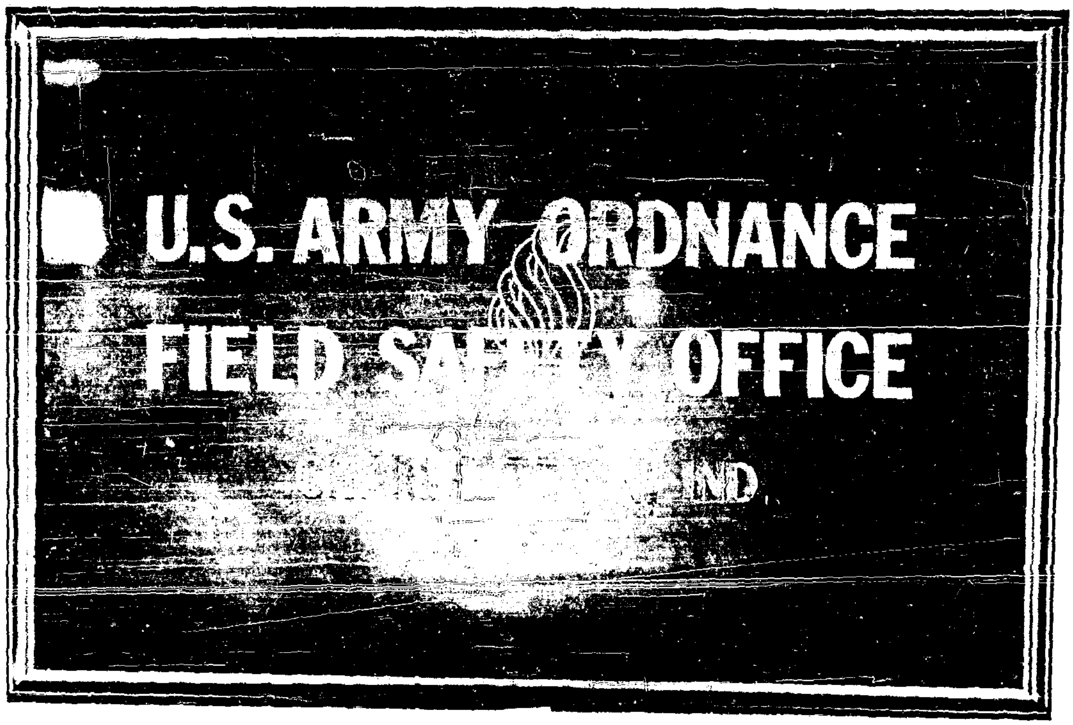
Col. Hamilton: Thank you very much Dr. Ball. We have to juggle our agenda a little to try to squeeze everything in. Col. R. H. Peter, the Commanding Officer of the U. S. Army Field Safety Office will tell us about the activities of his office including the Ordnance Safety School and U. S. Army Ordnance Safety Equipment exhibit. Col. Peter.

Col. Peter: It has been a pleasure for me to attend this Explosives Safety Seminar and I would like to take this opportunity to compliment Colonel Hamilton, Mr. Lowell and other personnel of the Armed Services Explosives Safety Board and our host, the Air Force, on the exceptionally fine manner in which this very successful meeting has been conducted.

The interest and active participation in this meeting of a large number of personnel from Government agencies and from the propellant industry has contributed to its success and is an indication that we are all on the same team as far as safety is concerned.

Because of your interest in safety I would like to extend a special invitation to all of you to use the facilities of the U. S. Army Ordnance Field Safety Office in connection with your safety activities. We would like to make Army Ordnance Safety Training facilities and activities available to personnel of the Air Force, Navy and industry as well as to all branches of the Army.

You can't very well make use of our facilities and activities unless you know what they are, so I am going to devote a few minutes to telling you about them.

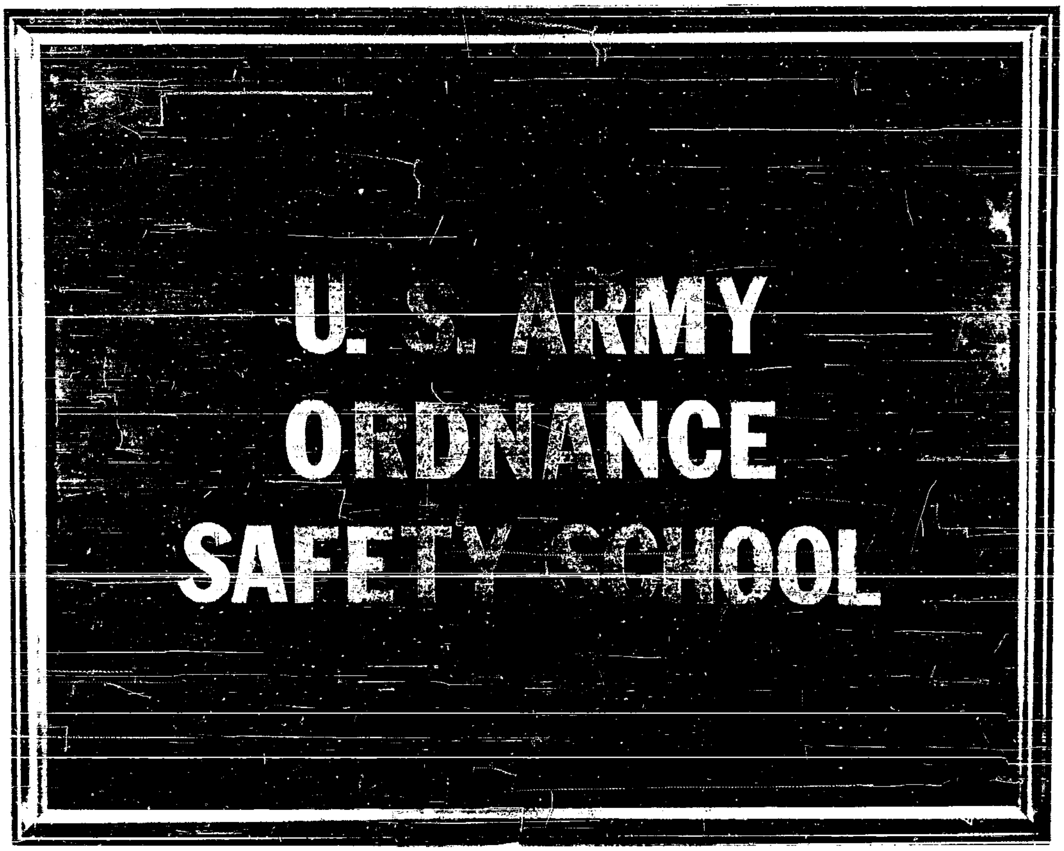


Slide 1

Our office is located at Charlestown, Ind. which is near Louisville, Ky.

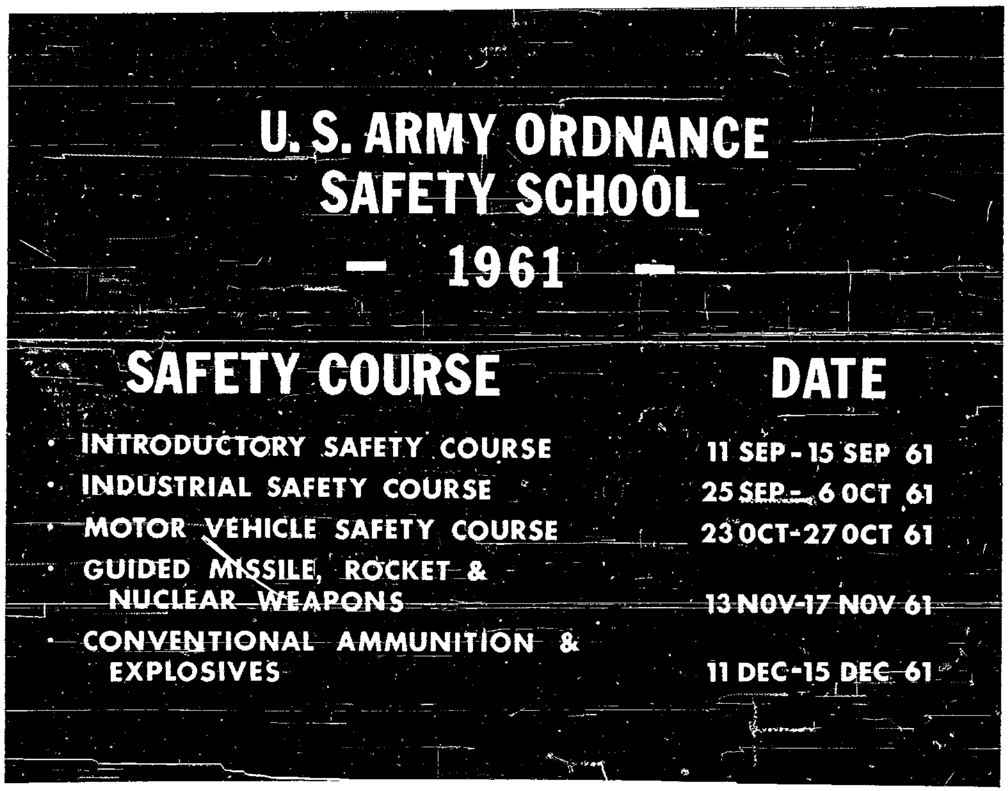
Slide 2

This area is known as the land of fast horses, pure water and beautiful ladies. You can interchange these adjectives and nouns to suit yourself.



Slide 3

One of our principle activities is the operation of the U. S. Army Ordnance Safety School.



Slide 4

This slide shows the courses which are available to your personnel during the balance of this year.

We have a course in guided missile, rocket and nuclear weapons safety scheduled for November which some of your people may be interested in attending. Copies of a brochure which contains complete information on our Safety School will be available to you near the door as you leave this meeting. This brochure contains the dates of courses scheduled for the remainder of 1961, as shown on this slide, and those for the first half of 1962, which are shown on Slide 5.

This brochure also contains descriptions of the courses and how to apply for attendance at them. There is another Guided Missile, Rocket and Nuclear Weapons Safety Course scheduled for February. Your personnel may attend the missile courses or any of the others on a space available basis. We are already close to capacity for all courses. So I would like to suggest that your people get their applications in soon if they are interested in attending any of these courses. Their applications will be processed on a first-come - first-served basis.

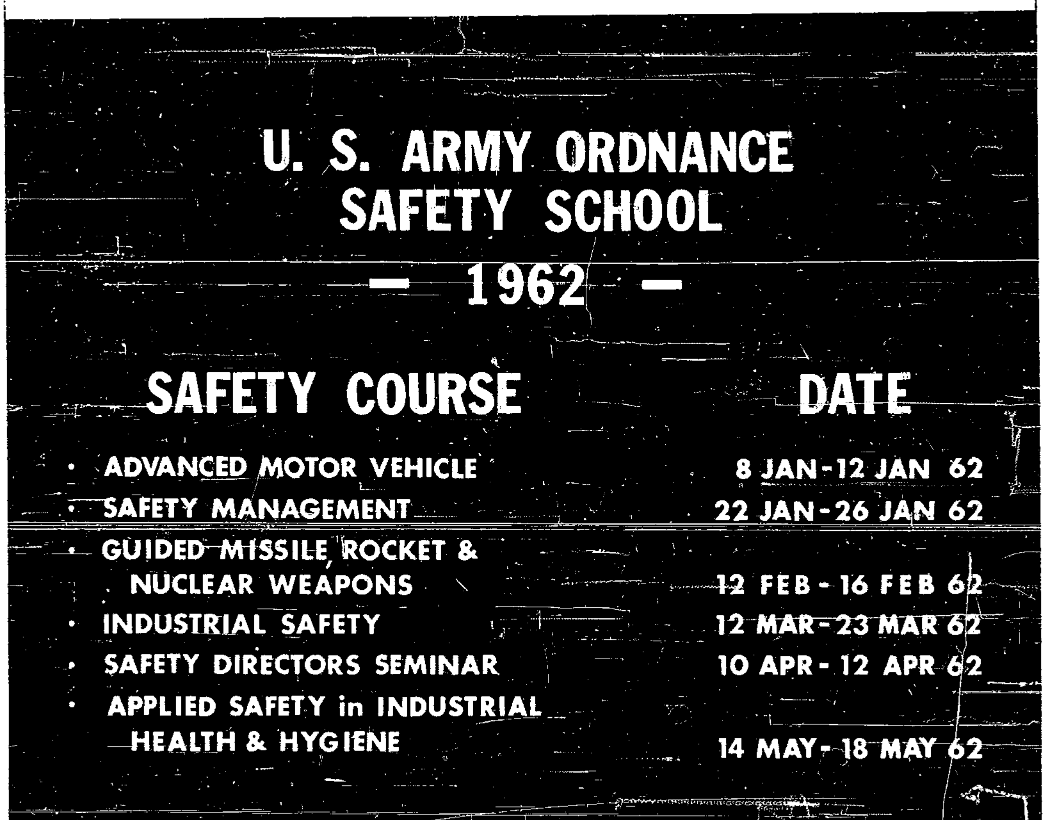
The Navy has reserved three spaces in each of our courses during 1961 and 1962. Naval personnel should send their applications to the Bureau of Naval Weapons. Army and Air Force personnel may send applications through normal channels to the Ordnance Field Safety Office. Industry personnel may forward applications through the Ordnance District in which they are located.

Slide 6 is a photo of our air-conditioned classroom, which is completely equipped with the latest training aids. All of our students are treated as gentlemen and VIP's and they tell us they find our courses pleasant and interesting.

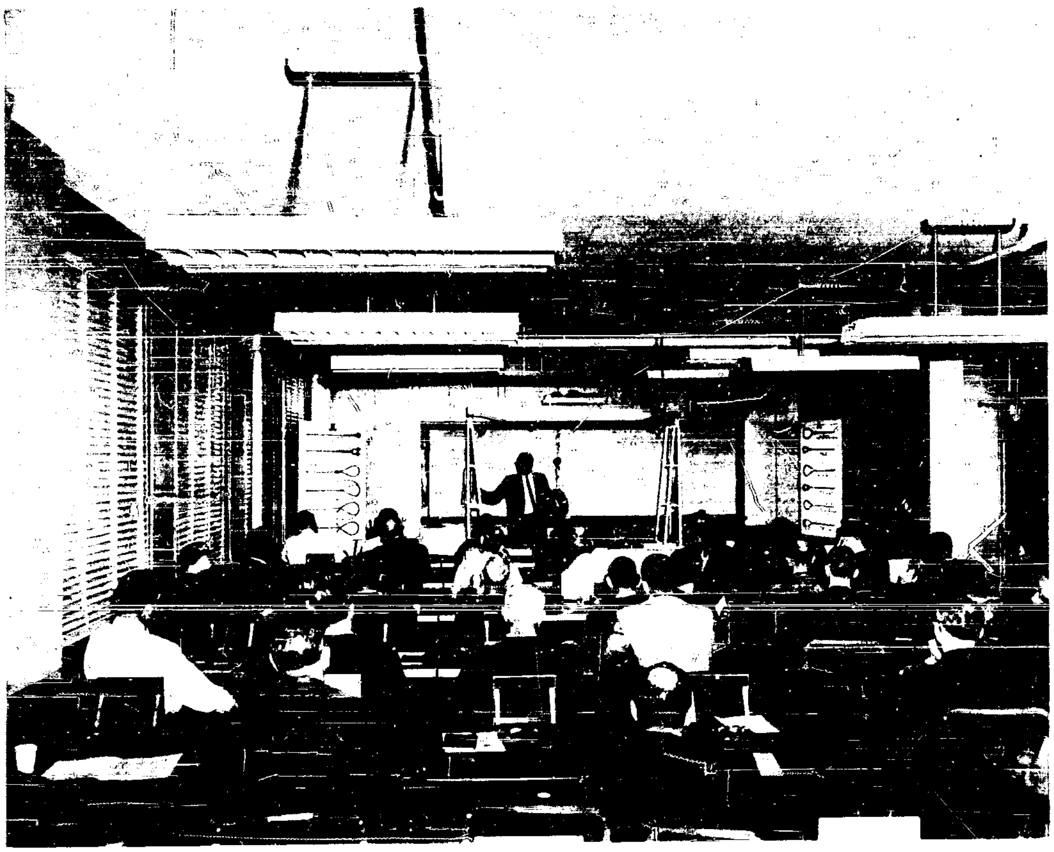
Courses are taught by safety engineers who are assigned to our Inspection and Investigation Divisions. These engineers conduct safety inspections and investigate accidents at 92 Ordnance activities and 120 privately-owned plants. They have had over 300 years of ammunition and explosives safety experience.

Slide 7 shows Harry Guest, Chief of the Inspection Division, and three of his safety engineers planning inspection schedules for 1962. By inspecting Ordnance Corps installations and privately-owned plants, we try to prevent accidents by eliminating unsafe equipment, facilities and practices.

I would like to show you 4 of the latest color photographs which are used as training aids in our school.

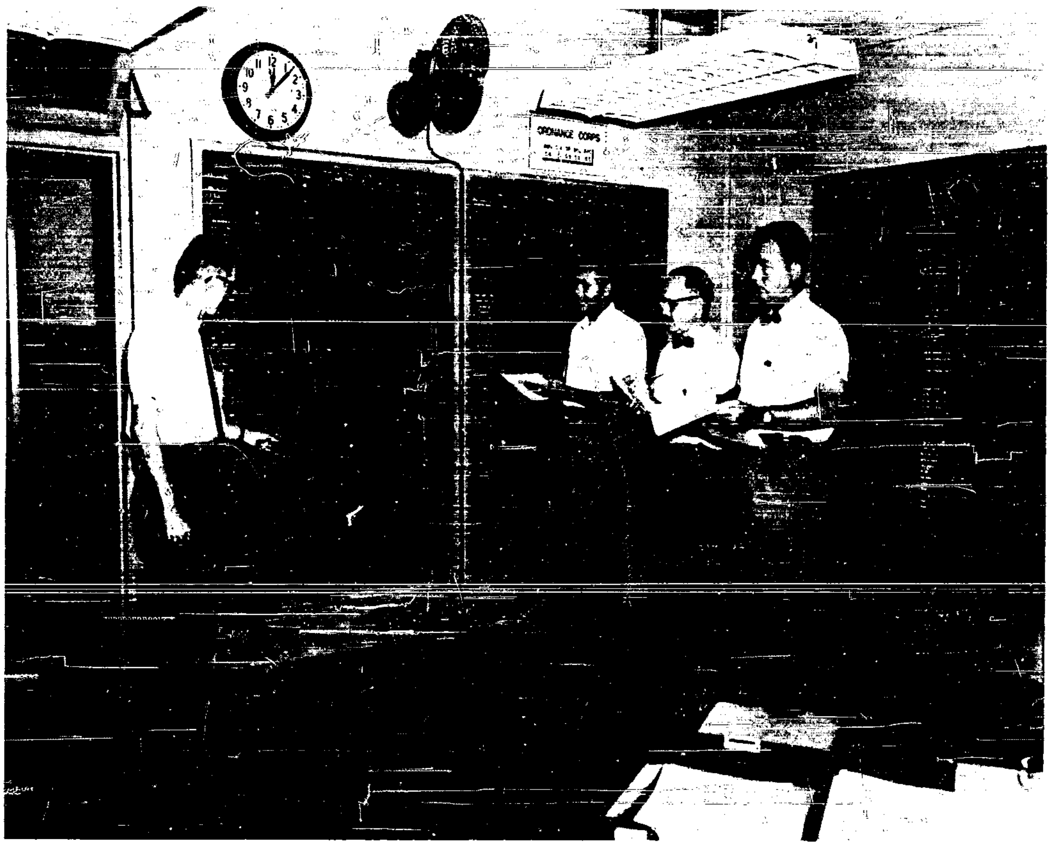

U. S. ARMY ORDNANCE
SAFETY SCHOOL
— 1962 —
SAFETY COURSE
DATE
• ADVANCED MOTOR VEHICLE
8 JAN-12 JAN 62
• SAFETY MANAGEMENT
22 JAN-26 JAN 62
• GUIDED MISSILE, ROCKET & NUCLEAR WEAPONS
12 FEB-16 FEB 62
• INDUSTRIAL SAFETY
12 MAR-23 MAR 62
• SAFETY DIRECTORS SEMINAR
10 APR-12 APR 62
• APPLIED SAFETY in INDUSTRIAL HEALTH & HYGIENE
14 MAY-18 MAY 62

Slide 5



Industrial Safety Course, US Army Ordnance Safety School

Slide 6

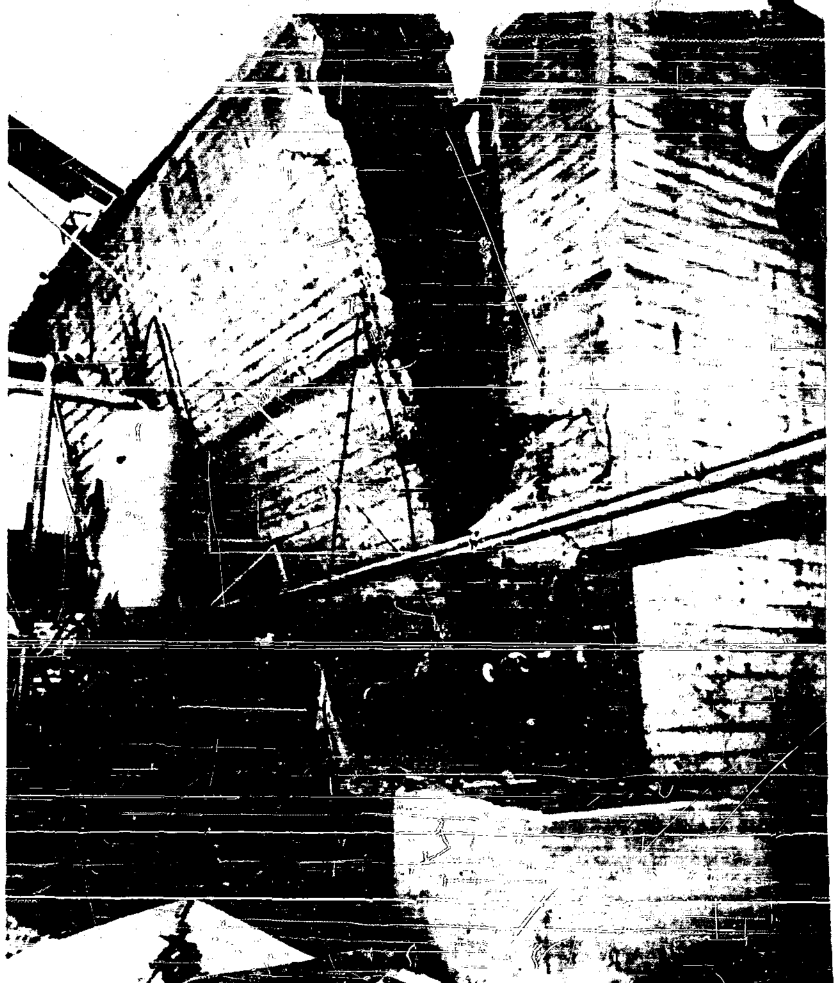


Harry C. Guest, Chief, Inspection Division and three of his safety engineers planning 1962 inspection schedules.

Slide 7

UNCLASSIFIED

WALL COMPLETELY CRACKED



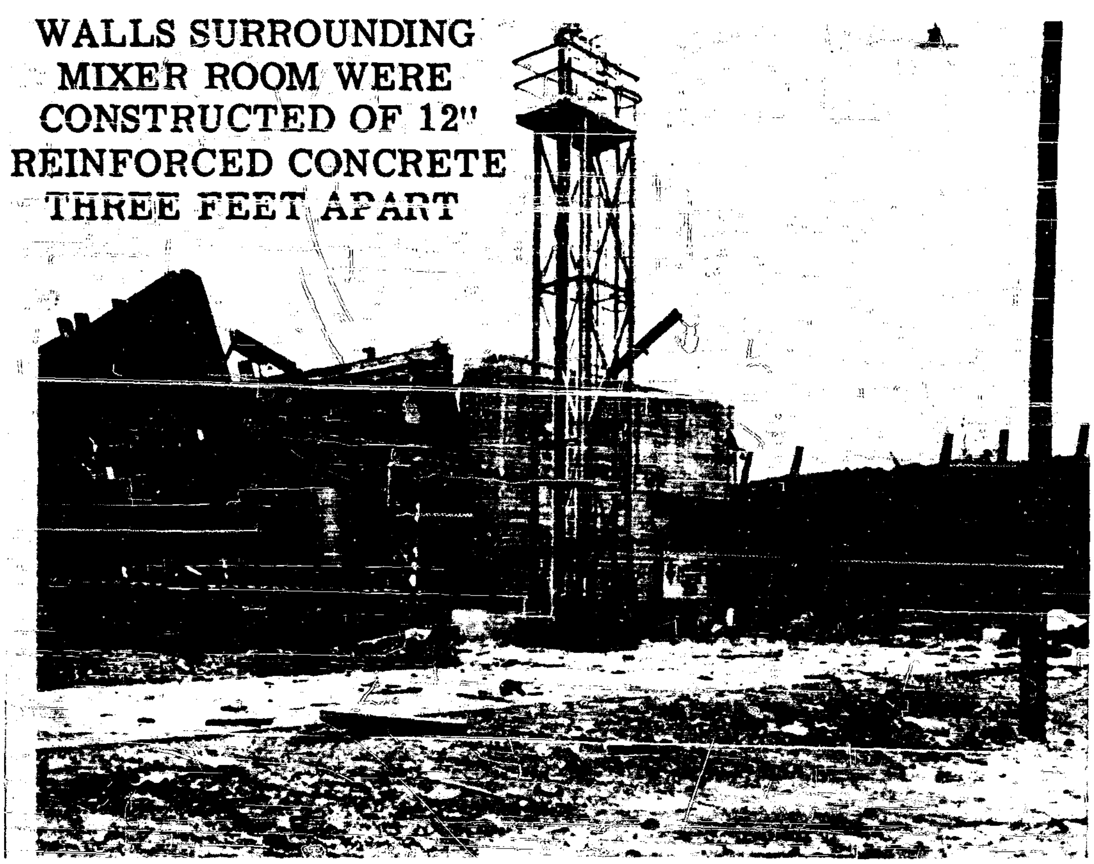
Slide 8

This photograph shows what was left of the inside of a mixer room after an explosion at an Army Ordnance Plant last month.

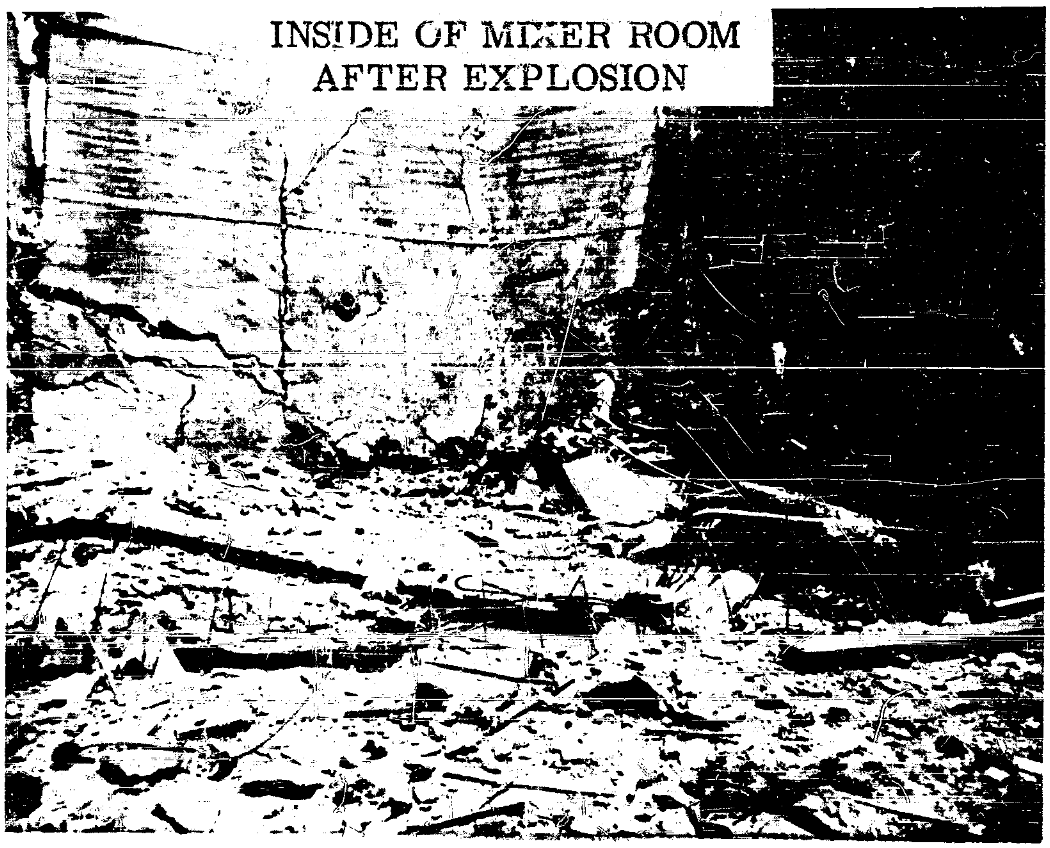
UNCLASSIFIED

Damages were estimated at $700,000.00 and 11 minor injuries resulted. Preliminary investigation indicated that the probable cause of the explosion was friction between metal parts and propellant in the packing gland areas of a Baker-Perkins mixer. Adjacent buildings, separated by the required quantity-distances, received extensive blast damage. This is an indication that our quantity-distances for high energy propellants may not be adequate.

The walls surrounding the mixing bay were constructed of 12" reinforced concrete three feet apart. The space between the walls was filled with earth - Slide 9. This photograph shows the damage to the walls surrounding the mixer. Notice the complete severance of the concrete walls in the center of the photo.



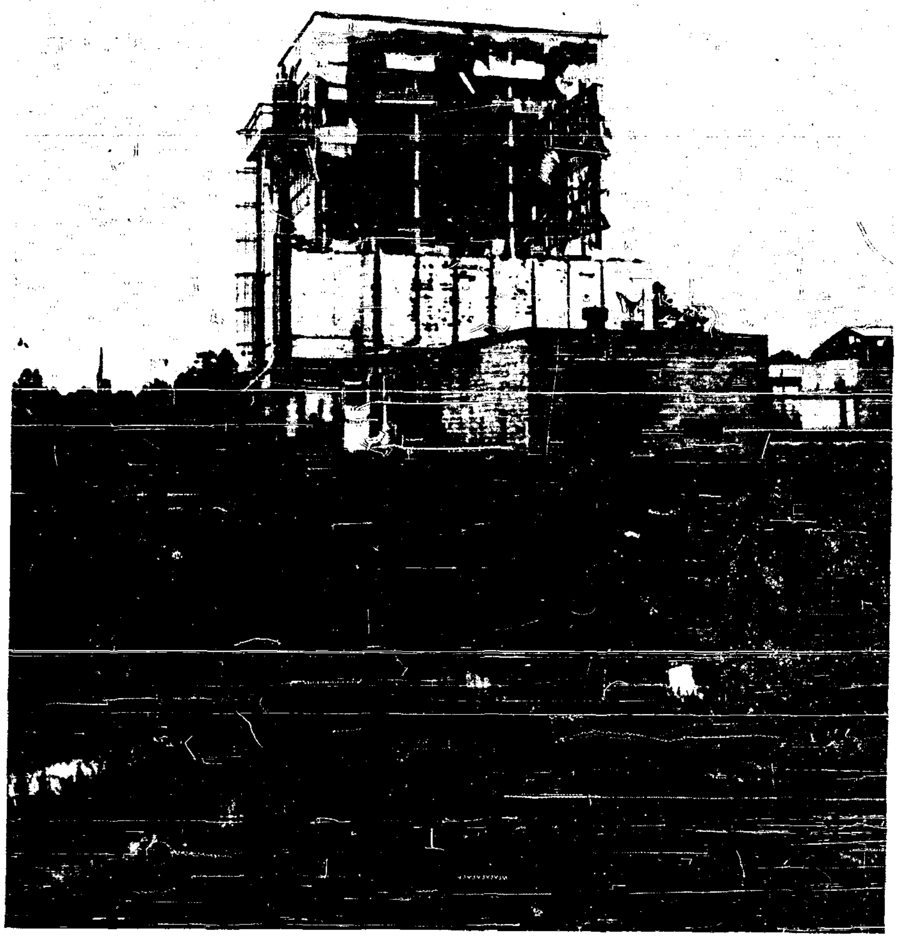
Slide 9



Slide 10

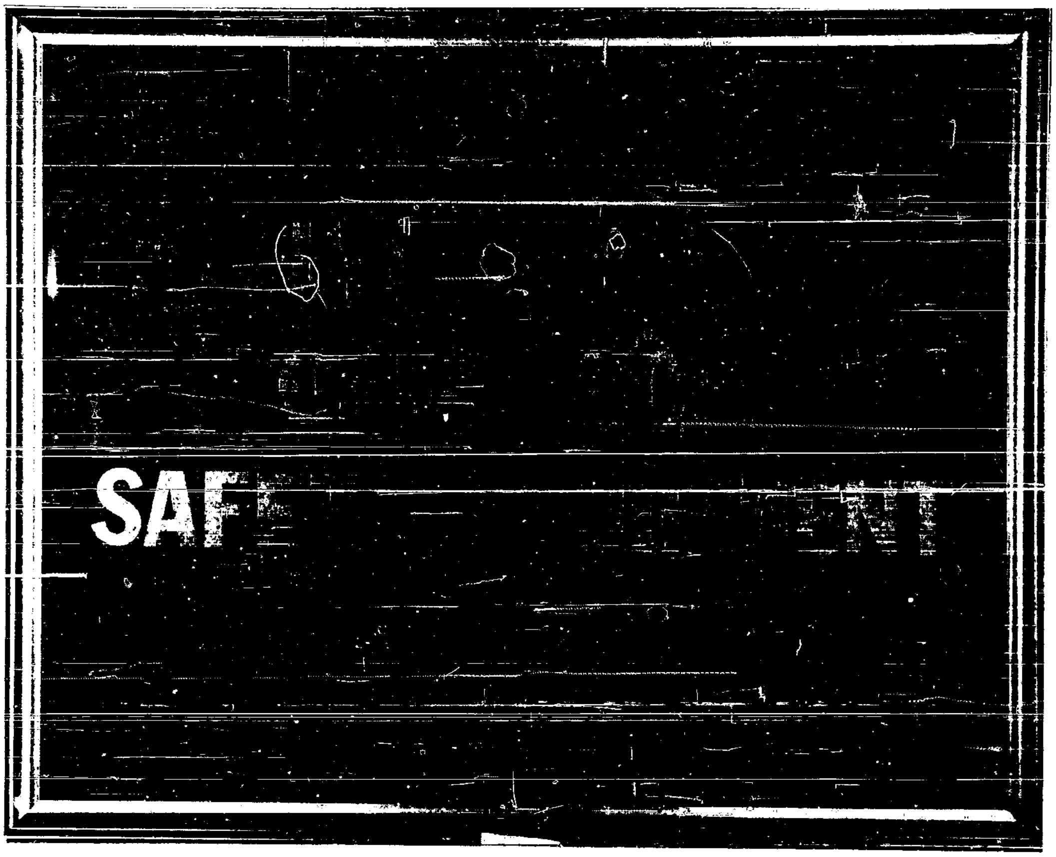
This photograph shows torn and twisted structural members and complete cracking of the concrete wall.

CUTBACK BUILDING
210 FEET FROM EXPLOSION



Slide 11

This cutback building was located approximately 210 feet from the explosion. Transite siding and corlox panels on this building were destroyed. Two persons working in the building at the time of the explosion received minor injuries.



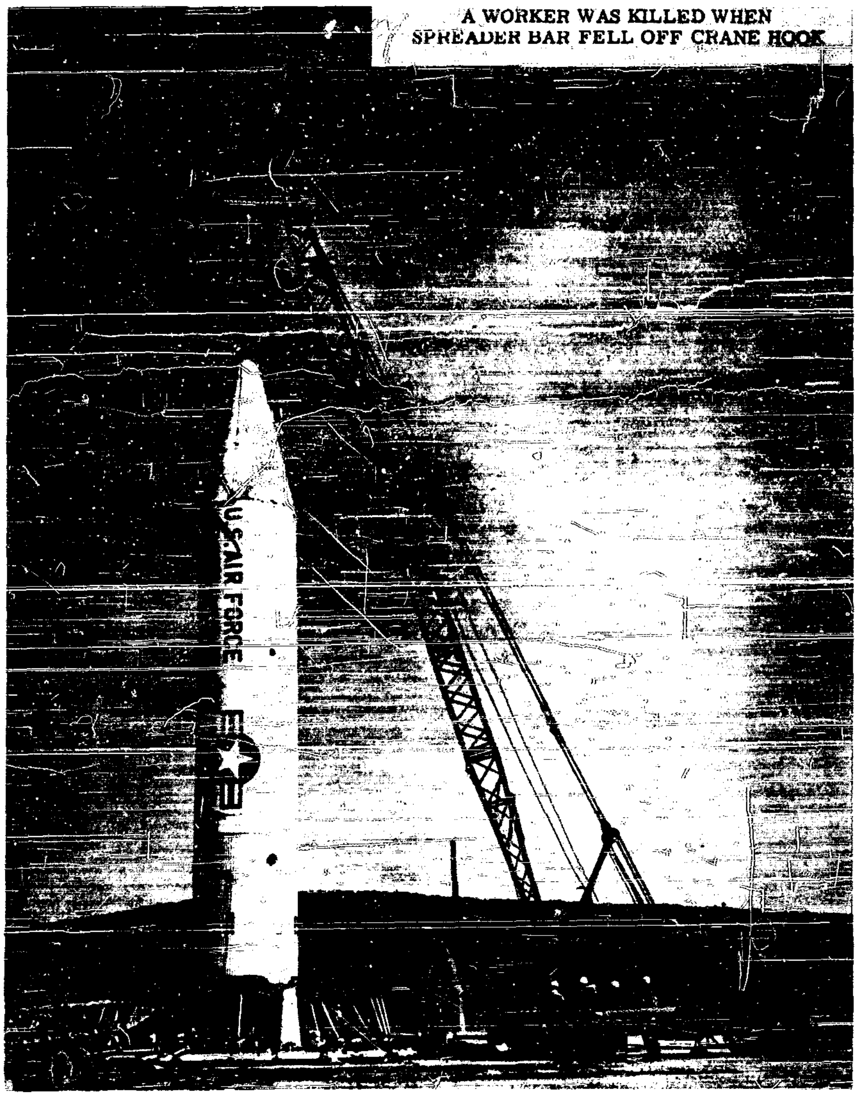
Slide 12

The U. S. Army Ordnance Safety Equipment Exhibit, which was established recently, is a valuable source of training aids for the school. Leading manufacturers of safety equipment who are genuinely interested in promoting safety have furnished over 300 items for this exhibit.

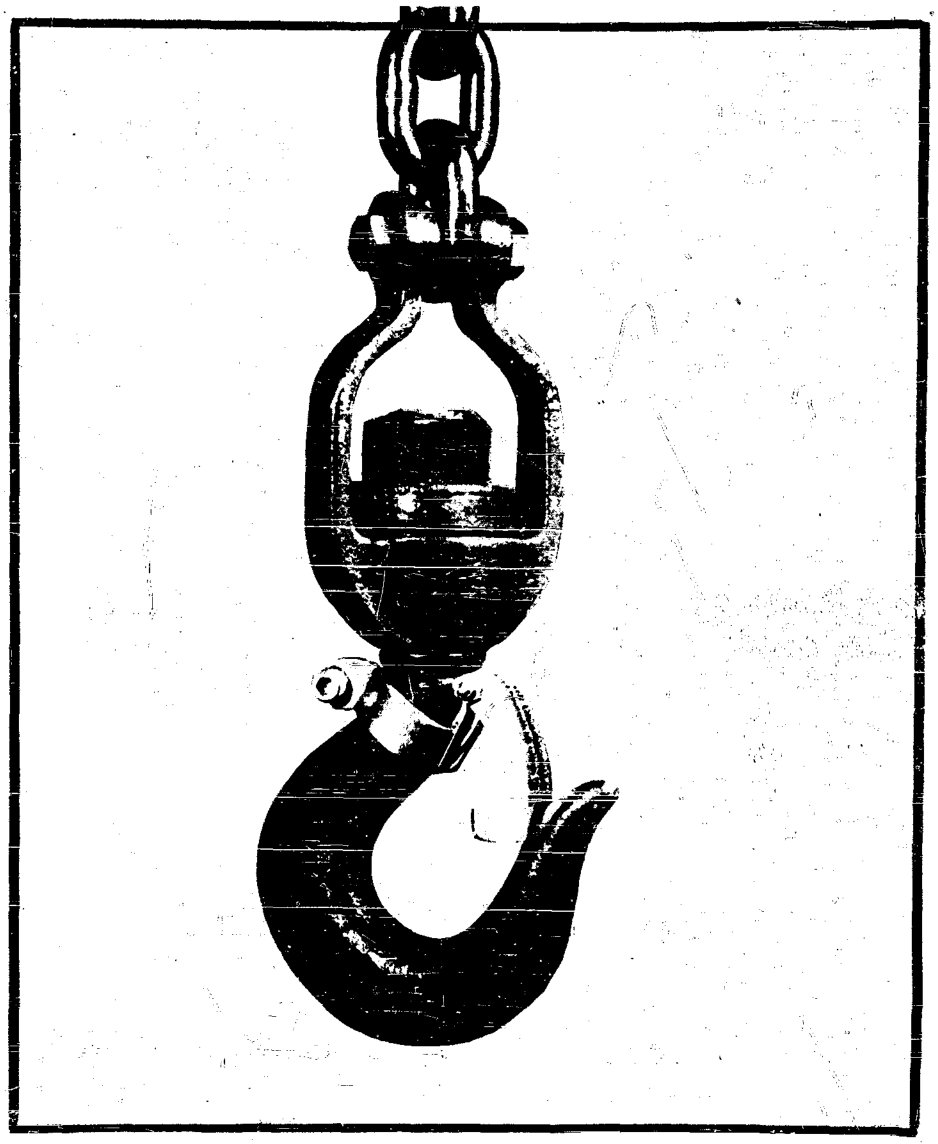
Students at Ordnance Safety School courses are given a complete conducted tour of the exhibit and selected items are used for instructional purposes in the classroom. A conducted tour of the exhibit is a safety education by itself. You do not have to attend the Safety School in order to visit the exhibit. We will be happy to have you drop in to see this exhibit whenever you are in the Louisville area. It is the largest permanent exhibit of safety equipment in the world and has been completely air-conditioned for the comfort of our students and visitors. Safety personnel and operating personnel should be thoroughly familiar with the latest safety equipment in order to prevent accidents and fatalities.

Slide 13

For example, this is a photograph of a routine Jupiter missile operation which resulted in a fatality. The crane operator was lowering the spreader bar which was attached to the crane hook. The spreader bar caught on one of the small nose cone projections and slipped off the hook. A workman standing below was struck on his head by the spreader bar and killed. He wasn't wearing a hard hat and he had no business standing under the crane.

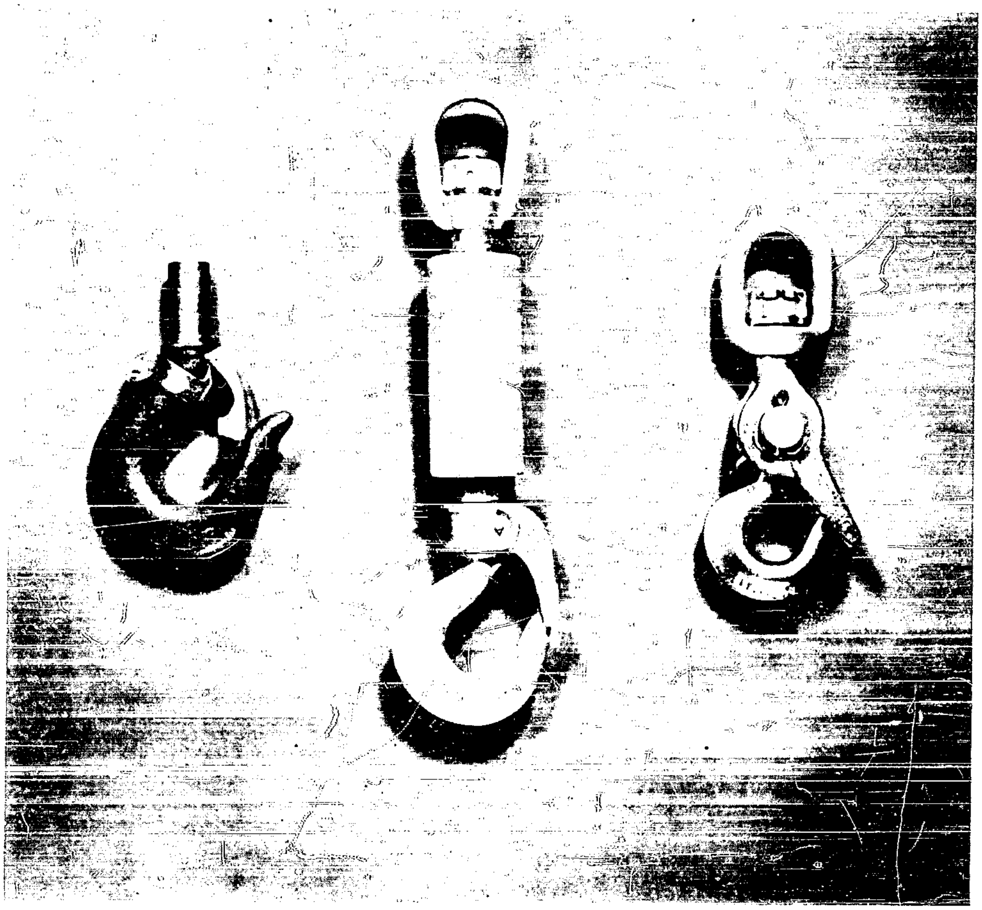


Slide 14



Slide 15

However, a safety latch like this on the crane hook would have saved his life. It costs only $2.75.

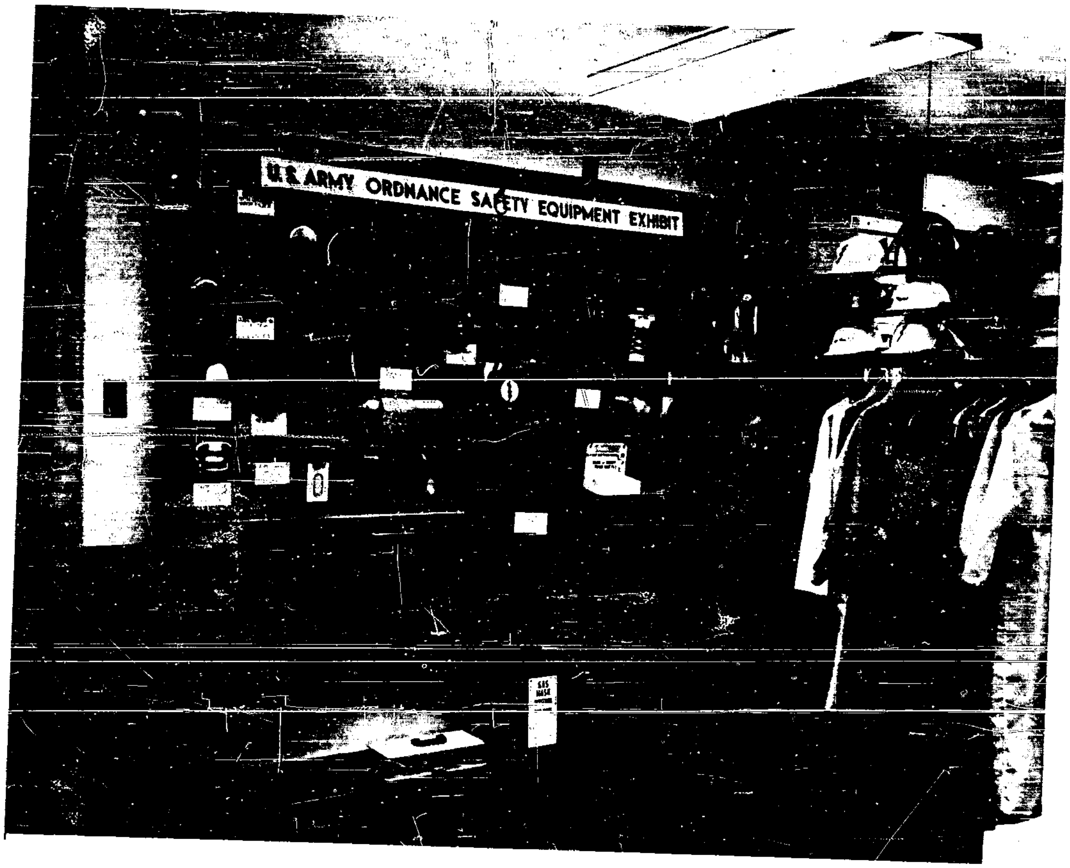


Slide 16

We have several different types of safety latches and hooks in our exhibit. Three of them are shown on this slide. None of these costs more than a few dollars. The use of any one of them would have saved a man's life.

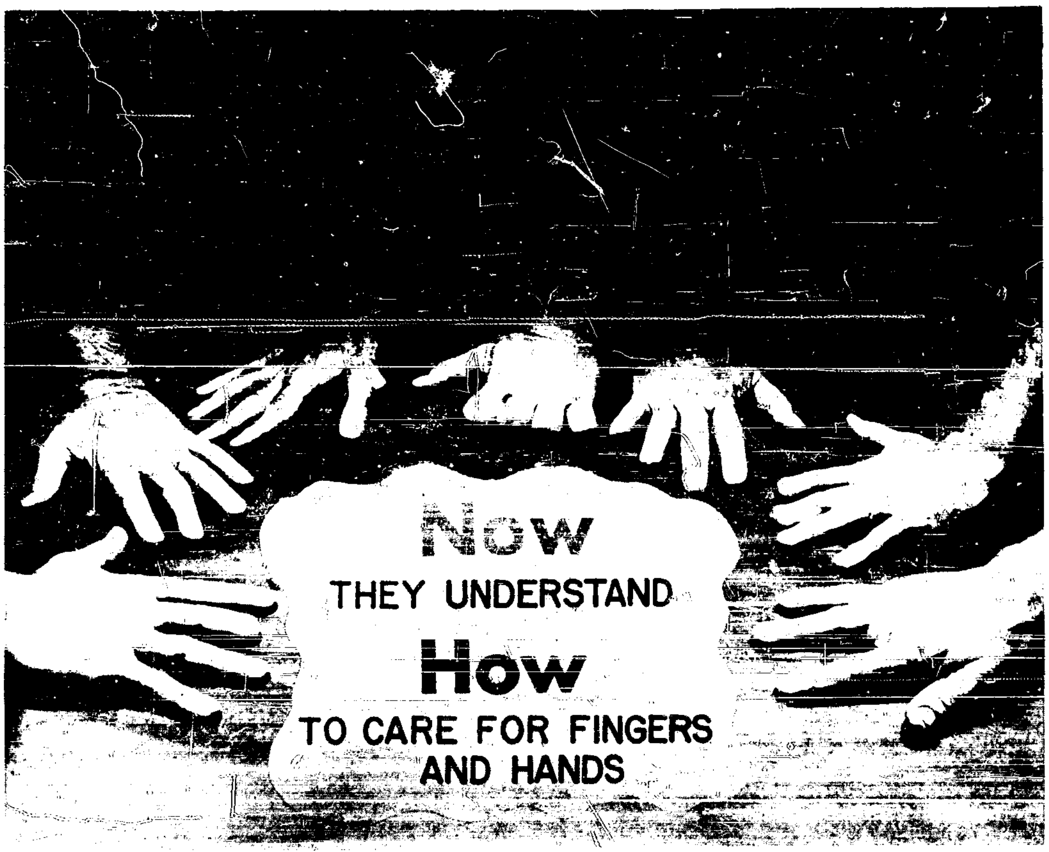
Safety items such as these safety latches and hooks are demonstrated to students in our courses and shown to exhibit visitors.

We also have the latest resuscitation equipment, firefighting equipment, deluge systems, machine guards, non-sparking tools, warning devices, safety hats, shoes and protective clothing.



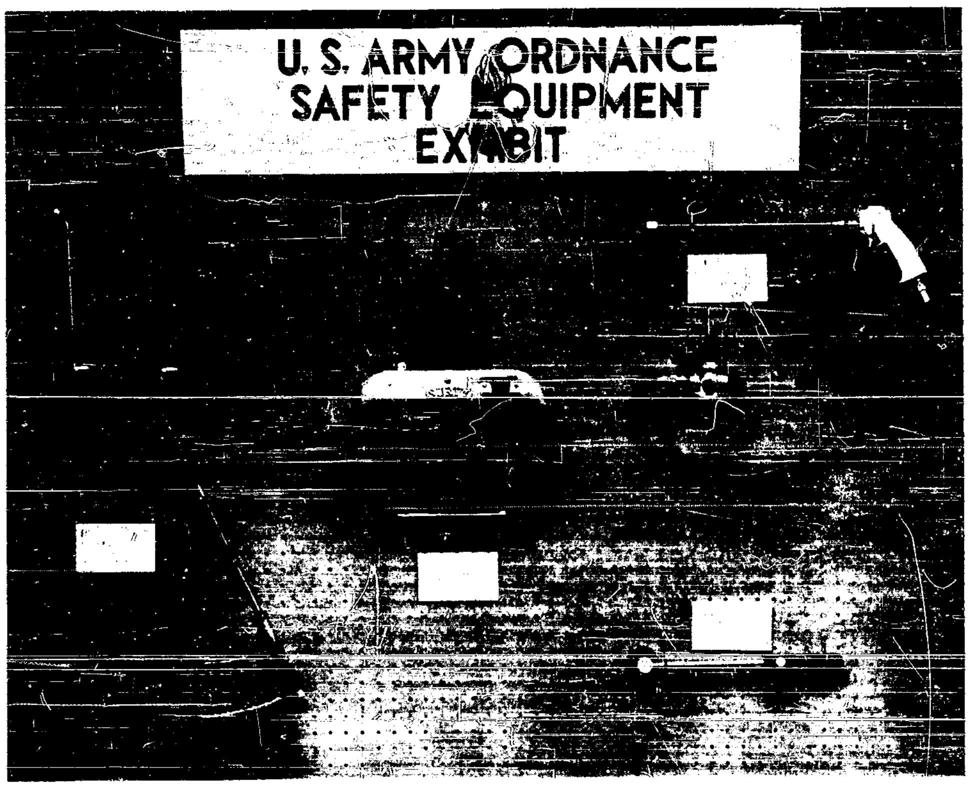
Slide 17

This slide shows Peck Bailey, one of our safety engineers, demonstrating the latest protective clothing for missile fuel handlers. He is wearing a rubber suit and a rubber mask with a plastic window. The rubber gloves have a slip joint fit that seals them to the suit.



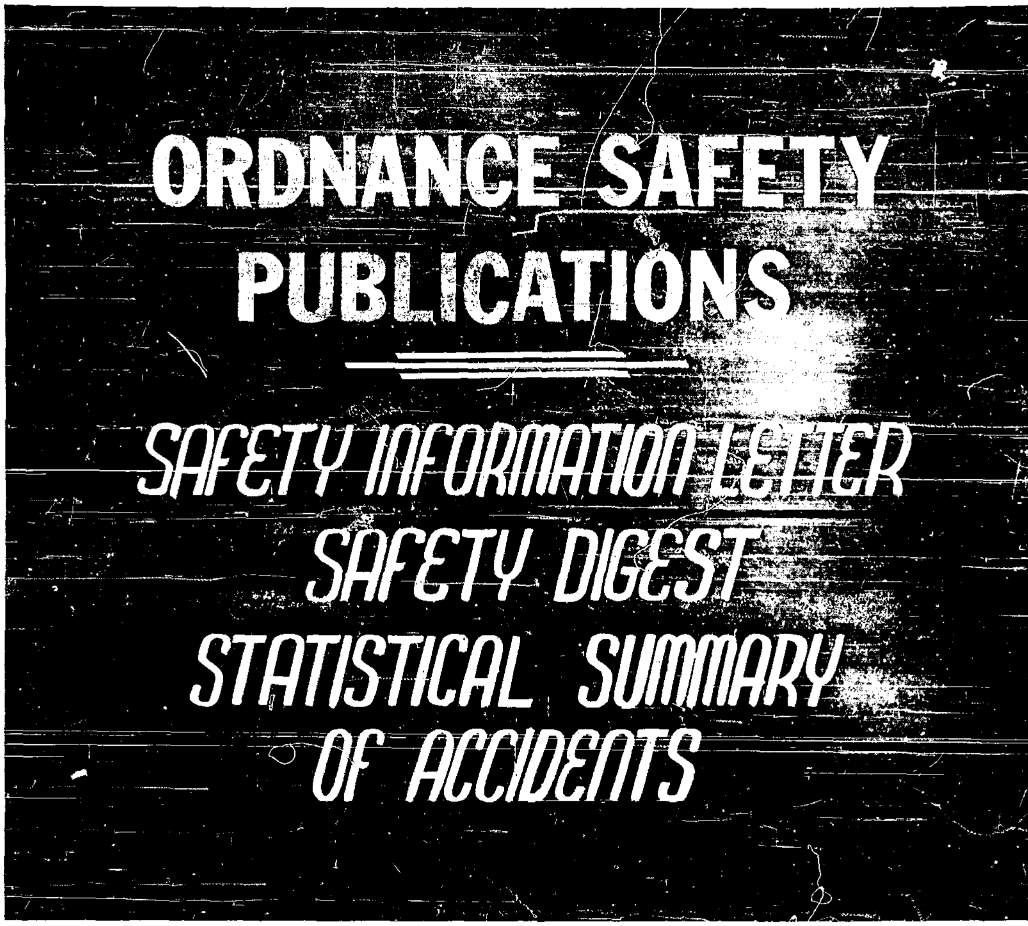
Slide 18

This slide shows 7 hands belonging to 7 men employed at one ordnance installation. These hands were involved in accidents which could have been prevented by the use of guards like these.



Slide 19

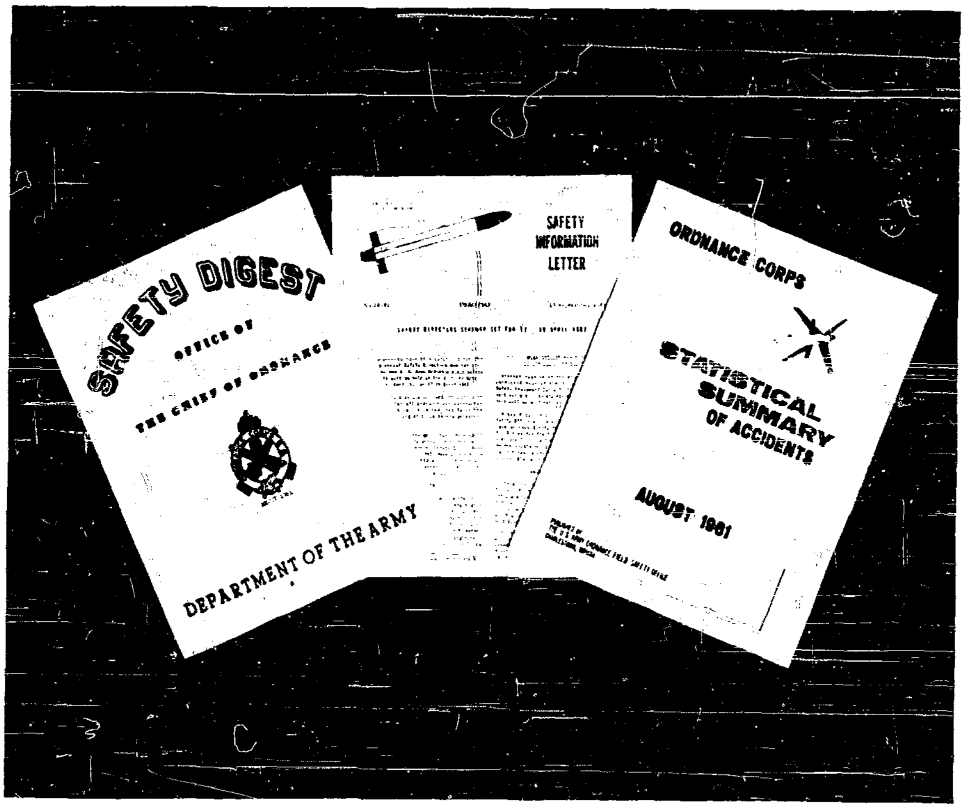
Students attending our courses are shown how to use these guards and - what is more important - how to get others to use them.



Slide 20

Army Ordnance publishes three monthly safety periodicals. The safety information letter specializes in short articles and the latest safety news.

The Safety Digest contains longer technical articles on all types of safety, including the manufacture, transportation and storage of high energy solid propellants. Statistical information on accidents, fires, explosions, injuries and fatalities is published in the statistical summary. This information is analyzed in an effort to spot accident trends which may be developing at our installations. Corrective action can then be taken before too many accidents occur. Although this statistical information pertains to Army Ordnance installations and contractors, it may be of interest to Air Force, Navy and industry personnel for comparative and trend spotting purposes. Sample copies of these publications are available and may be picked up as you leave this meeting.



Slide 21

Slide 22

With the world situation as it is, we must do everything in our power to prevent accidents, injuries, fatalities and property losses. We can't afford to lose trained personnel or essential production facilities as a result of accidents. The end result is the same whether we kill people and blow up buildings through accidents or our enemy does the job with a nuclear warhead. This is the time for us to get on the ball safety-wise and stay on the ball. Thank you.

Col. Hamilton: Thank you Col. Peter.

Col. E. S. Howarth, DIG/S, Norton AFB: I'd like to tell you about the deliberations of our committee which was convened to discuss ways and means of getting accident and incident reports not only to the military departments but a flow of information to industry itself. It's our unanimous consideration and recommendation that the Explosives Safety Board convene and chair an AdHoc Committee to explore all facets of this subject and to come up with an incident-accident reporting and information distribution system. The committee also feels that there is a great deal of urgency on this requirement and recommends immediate action by the Board to convene such an AdHoc committee and recommends immediate action by the AdHoc committee.

Col. Hamilton: Thank you Col. Howarth. We will do this as soon as we get back to Washington. I'd like to state in connection with this that one of the most important things is for all of you to send in reports on such incidents and accidents as you have and this should include the relatively small ones which have not been reported in the past because these small ones can cause a lot of trouble. Mr. Kilgore wants to make an announcement.

Mr. D. B. Kilgore, Wright-Patterson AFB: If any of you people have any problems relative to identification of remains in incidents there are trained people at Hq AFLC, formerly Hq AMC at Wright-Patterson AFB, Attn: MCAM. These men have been in the business around 15 years and they had a lot to do with training this special team that is now with the FBI and they are involved in all identification in aircraft accidents. So if you are unfortunate enough to have an accident and need help, I'm sure they will be available to help you.

Col. Hamilton: Thank you Mr. Kilgore. Mr. H. E. Offenhauser who represents the Guided Missile Range Division of Pan American World Airways at Cape Canaveral will present "Government and Industrial Practices in Establishing Safety Criteria for High Energy Solid Propellant Storage and New Problems Encountered in the Field of Longevity in Storage."

Mr. Offenhauser: I will speak this morning on two subjects, My first subject will be "Problems on Longevity in Storage."

The rapid development of propellant technology has created a unique challenge to the user and storer. Storage facilities have not kept pace with the developer in designing and constructing adequate facilities and sites.

Pan American World Airways is responsible to the Air Force Missile Test Center for the planning, engineering, and operation of the Atlantic Missile Range. Pan American is charged with the responsibility of providing adequate handling and storing facilities for all propellants and explosives tested on the Atlantic Missile Range.

The storage facilities at Cape Canaveral at the present time consist of seventeen standard "igloo" type magazines of reinforced concrete with drainage and lightning protection devices. Thirteen of these magazines are 26 feet by 40 feet by 60 feet and are equipped with a monorail and chain hoist; the other four magazines are 15 feet by 19 feet without the monorail and chain hoist. Only two of the large magazines are temperature and humidity controlled. We also have three assembly type magazines assigned to "Minuteman" Project, which are designed with a blow-out roof and has an explosive load limit of 100,000 pounds.

These magazines are located in two areas, Storage Areas 2 and 3. Storage Area 2, which contains nine magazines, is located outside of all launch danger areas and is our main area. This area is used to store all propellants and explosives currently in use. Storage Area 3, which contains eight magazines, is located inside the launch danger area for so many complexes that it is used only for a holding area and obsolete ordnance storage.

With these existing storage facilities, we are finding it extremely difficult to meet the requirements of adequately storing propellants that are currently undergoing tests at Cape Canaveral.

We are presently testing a solid propellant motor at Cape Canaveral, and due to its size we are unable to store it in any of our magazines. This motor has to remain outside in its shipping container, which is temperature and humidity controlled, until called for by the contractor for assembly.

There will be many problems of this nature with future motors that are now in the design stage. Solid propellant motors of multi-million pounds thrust far exceed the capabilities of our existing storage facilities.

The first consideration that should be given this problem is transportation. The problems of packaging and transporting a motor of this size are many.

Another consideration is the environmental requirements which will have to be maintained from the manufacturing site to the storage site. A method may have to be devised to remove toxic or explosive gases during transportation.

When the motor reaches its destination, there is the problem of off-loading it from its carrier and storing it. Also, special considerations will have to be given to emergency procedures such as firefighting during transporting and in storage. The required position of the motors in storage, the possible rotation of these motors and the possible provisions for special grain inspection such as gammagraph, X-ray or optical must be considered.

The problems of storage are many and varied. Storage facilities are using last years' technology in designing sites to store this years' missile product. There will have to be a coordinated program of planning between the manufacturer and the storer to determine storage facility requirements. Enough time must be allowed to design and construct adequate facilities to receive and store the manufacturers product.

My second subject is "Government and Industrial Practices in Establishing Safety Criteria in Storage." The rapid development of propellant technology has created a unique challenge in establishing safety standards for the handling of these high-energy materials. Notable progress is being made by the developers even though the art and science is relatively new and sometimes the material properties are not completely known.

The three major points in propellant fuel handling are toxicity, fire and explosive dangers.

Toxicity can be broken down into three phases; detection, protection and treatment. The toxic nature of a propellant will vary with the particular substance. Take beryllium additives as an example. There are in production, constant monitoring instruments that are capable of detecting as low a concentration of beryllium particles as two micrograms per cubic meter of air; a safe concentration. Only normal clothing of the coverall type is required to protect the worker. Respiratory equipment need only be of the dust type with a filter.

There is no specific treatment for over exposure cases. General supportive measures should include the use of oxygen. Immediate removal from the exposure is very important. So little is known about beryllium poisoning and its subsequent reactions that it is wise to set up safety regulations regarding it. Many other propellants, oxidizers and additives present the same problems as beryllium.

Fire and explosive dangers can be combined. The typical questions that must be answered are as follows: Is the substance

impact sensitive? Is it spontaneously flammable when it comes in contact with other materials/ Does it make them pyrophoric? Can it be controlled or extinguished if on fire? Will it react with other materials to produce detonation?

Tests are continuously being made by the developer of a propellant to determine the answers to these questions. These tests continue on through the development of the motor itself, usually beginning with micro quantities of the propellant under development. A great deal may be known about the substance or nothing at all. To determine the sensitivity of the propellant, it is subjected to a drop weight test. To measure the effect of heat on a given propellant, micro samples are run through a thermal stability tester.

The explosive force of a propellant is measured by many methods. One method is the dent-plate test. This gives a direct reading in millimeters of the depth of a dent caused by the explosion.

The answers to all these questions determine the explosive classification assigned and any special handling requirements.

The results of these tests on the propellant and the motor in most cases remains at the manufacturing site and never reaches the user.

There should be some method for the dissemination of this information to the using organizations through safety manuals, special training manuals or training courses at the manufacturing site. There should be a broader distribution of information relative to safety such as reports of accident investigations and also any special precautions that the user should be acquainted with if new safety problems become apparent to the manufacturer.

The Ordnance Safety Manual is the final authority in the determination of propellant handling practices. This manual determines storage requirements, processing procedures, personnel limits, facility construction, types of buildings used and the inter-line and intra-line distances between buildings and facilities. If the present Ordnance Safety Manual is used to determine space and area limitations for future high-energy solid motors, we will find ourselves, the manufacturer and the user, pushed out of a place to operate. This manual is in the process of being brought up-to-date, and it will include high-energy fuel storage and handling procedures. Once these procedures are accepted, they should be used by the manufacturer in his research and development laboratories, in his pilot plants and in his production plants,

as well as at test sites such as CCMTA. In this way we will have continuity in the overall handling and storage of high-energy fuels.

The hazards of high-energy propellant handling and storage are being lessened with each new advance in safety. We can provide the physical protection to guard against human error; but our best chance for success in safety lies in the dissemination of all the information about a given propellant both to the manufacturer and the user. In this way we will have a complete understanding of all the hazards that face us.

Mr. McQueen: What problems do you anticipate with accoustical levels in your flight test facilities, and how are you planning to accommodate these?

Mr. Offenhauser: This is out of my field. There is another organization working on this, I couldn't tell you that.

Col. Hamilton: Would anyone in the room care to comment on that?

Mr. Thibodaux: We've had a group of people who have been studying this particular problem for awhile, people who have been in this business of aircraft noise for about 15 years. In fact even at Langley Research Center, we have a large blow-down tunnel which operates about 150 times a year which puts out the same noise as an Atlas Missile does when it takes off in flight. Our people have worked approximately 150 to 200 yards from this and some of the buildings sustained sound levels as high as 140 decibels and we have no problem. We have other inhabited areas inhabited by military housing on the field, and these areas actually sustained noise levels about 125 decibels. They are approximately about 5,000 or 6,000 feet away from this site and we have yet to have a single complaint about noise. Taking a look at the various boost systems we're talking about, where we use large solid boosters for example in the Apollo program or where we use large liquid boosters, when you compare solids and liquids both of which are required to do the same type of job, you find out that at any given distance away from the launch site that there's only about 1.6 decibel level difference between the noise that would be put out by a large solid as compared with a comparable liquid which would do the same job and we feel that a lot of the noise that has been going around about noise is kind of unfounded or certainly has no real good logical basis for changing location of some of the launching sites.

Mr. Ullian: I might mention that the talk I will give this morning intends to cover the national lunar program and part of this will cover the accoustic siting problem.

Mr. Keim: I'm wondering if you have a simple method for the disposal of small quantities of beryllium other than digging a hole 40 feet deep or deep-seaing it?

Mr. Offenhauser: No, we don't have any other ones, does anybody else?

Mr. Keim: How do you dispose of it. In other words, do you return it to the vender or bury it or send it out to deep sea, is this your method?

Mr. Offenhauser: If it was still in it's container, we would send it back to the vender.

Mr. Keim: I'm not speaking of powdered form, I'm speaking of perhaps machine parts, small machine parts. This might be in pieces as small as a hair, might be as thick as a pencil, but in small pieces, an inch or two inches long.

Mr. Offenhauser: No, I don't believe we have.

Lt. R. L. McArthy, BuWeps: There is quite an extensive beryllium recovery program, really very expensive, but it is recovered and re-used.

Mr. King: This is not my area, I think a medic should be answering this, but I don't believe there is any hazard with small metallic parts of beryllium, the hazard is rather with 10 micron sizes or less or things of this sort. Isn't this correct, and we handle beryllium like any other metal.

Mr. Offenhauser: This is true, but we're talking of beryllium in the small micron sizes.

Mr. King: I meant in answer to the gentleman's question about machine scrap and things of this sort. That just isn't a safety problem.

Mr. Offenhauser: This is true, it isn't.

Col. Hamilton: Thank you very much Mr. Offenhauser. Our next speaker is Mr. Thomas L. Logan, Chief of the Propulsion Branch in the Electro-Mechanical Laboratory at the White Sands Missile Range. Mr. Logan will make a presentation on the "Correlation of Safe Storage Temperatures for High Energy Propellants with Auto-Ignition Temperatures."

Mr. Logan: Beginning in August 1954, White Sands Missile Range became interested in the environments which would produce ignition, case rupture, or detonation of solid propellant rocket motors. The slow application of heat to complete rocket motors and Jato units was one of the environments applied. The primary interests were whether detonation of the propellant or ignition, possibly producing case rupture, would occur and the extent of hazard which would result. The possibility that critical temperatures might be reached in open desert storage or in missiles emplaced on launches was not considered. Rather, the principal concern was the possibility of shipping accidents, fires, and storage in such places as ships' holds or on submarines, possibly adjacent to steam lines.

The tests were conducted singly by circulating heated air through an insulated shroud containing the rocket motor. The air was heated with electric strip heaters which were housed in a separate compartment connected to the motor shroud with flexible ducts. Various heating rates were applied and temperatures of the heated air, motor surface and propellant, inside the grain perforation, were monitored. A number of slow heat tests were conducted with 8" diameter aircraft Jato units loaded with double base propellant and with 2½" diameter rocket motors loaded with polysulfide-perchlorate composite propellant.

At present some tests are being conducted on 10" diameter rocket motors containing a double base propellant. These te[illegible]s are designed to show the storage temperature and duratio[illegible] of exposure which will produce auto-ignition of the par[illegible]ular motor undergoing test.

Although the tests have only be[illegible] results from one test are included in this discussion

Heatir[illegible] rates f[illegible] three motors containing composite propellant ran[illegible] from 64.2 to 187.8°F per hour. All motors ignited [illegible] experienced case rupture followed by low-pressure b[illegible] of the propellant. An ignition temperature of 314[illegible] was recorded inside the propellant cavity for one of these motors. This was the only test from which propellant tempe[illegible] was recorded.

Seven aircraft Jatos containing double-base propellant were tested at heating rates ranging from 76 to 2.1[illegible] per hour. The results are tabulated below:

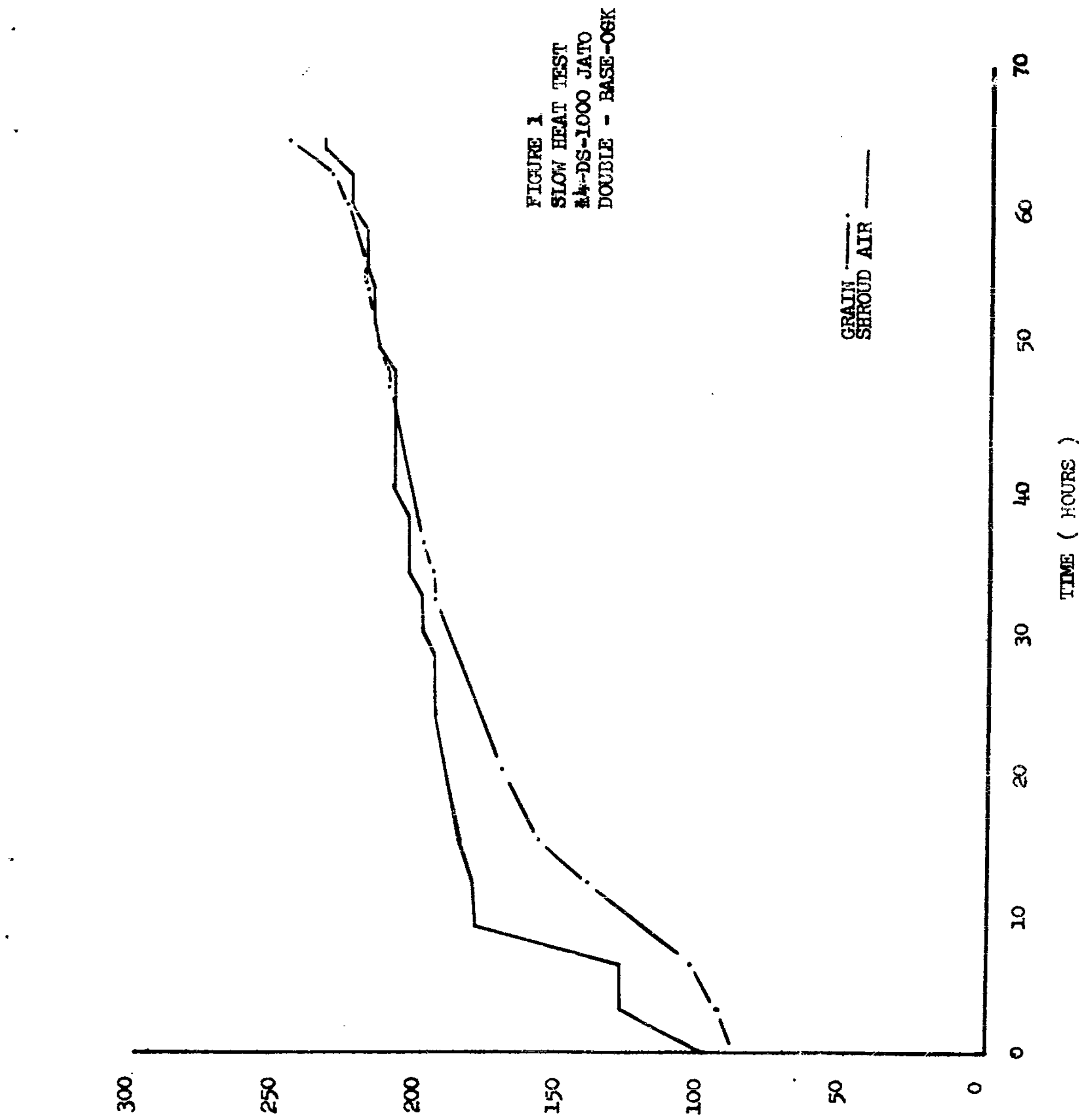


FIGURE 1
SLOW HEAT TEST
14-DS-1000 JATO
DOUBLE - BASE-OGK

UNCLASSIFIED

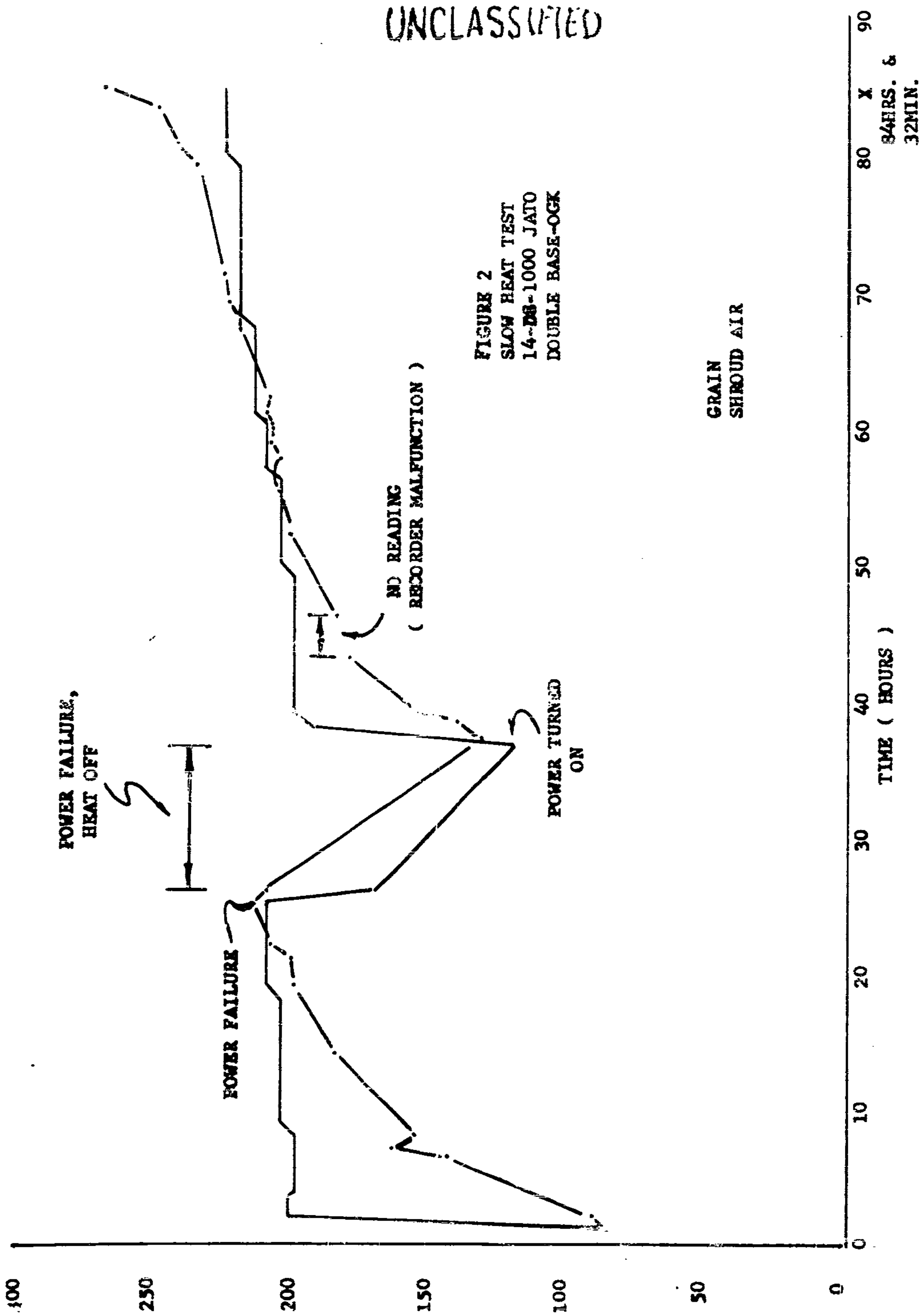


FIGURE 2
SLOW HEAT TEST
14-DS-1000 JATO
DOUBLE BASE-OGK

UNCLASSIFIED

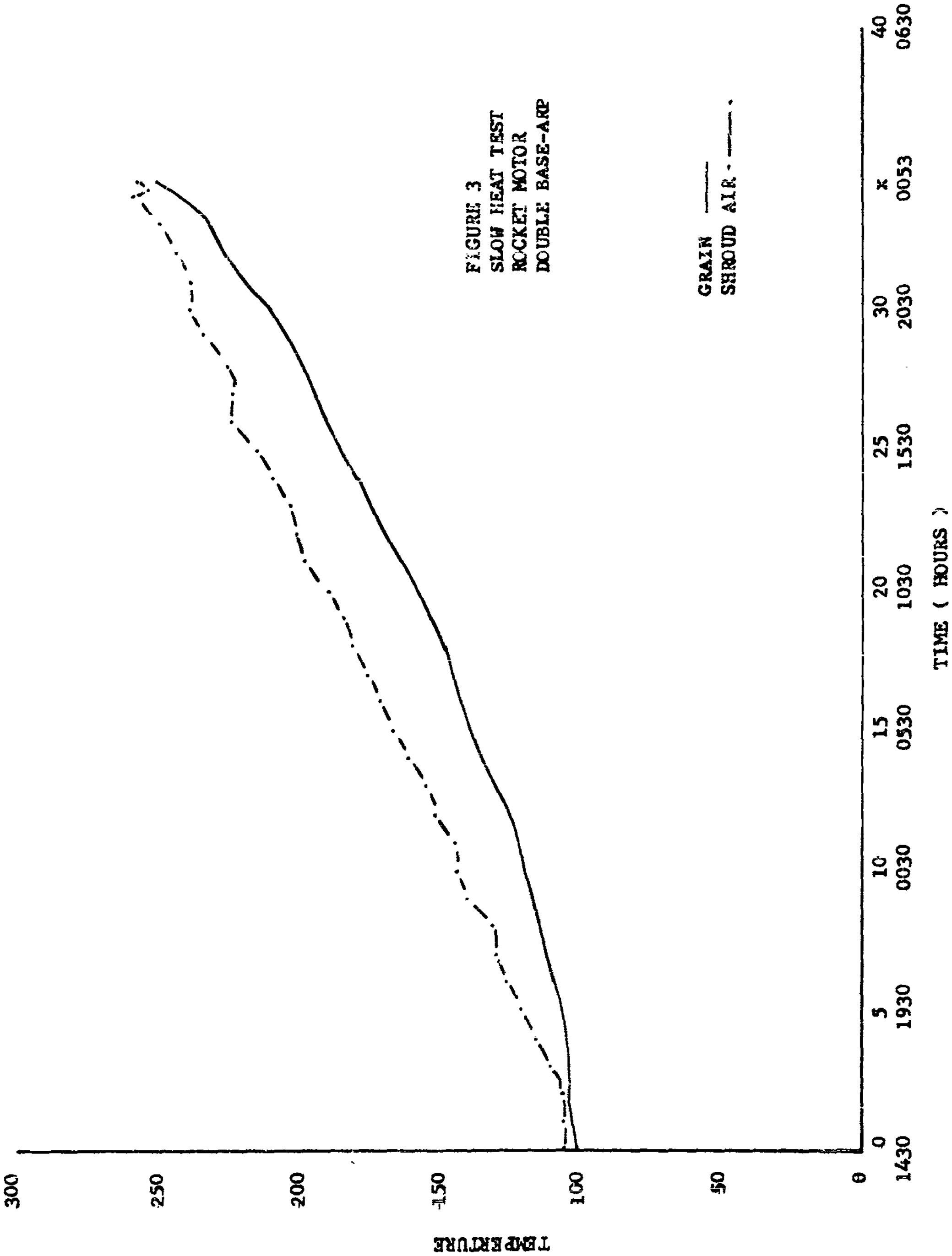


FIGURE 3
SLOW HEAT TEST
ROCKET MOTOR
DOUBLE BASE-ARP
GRAIN
SHROUD AIR
TEMPERATURE
300
250
200
150
100
50
0
TIME (HOURS)
0
1430
5
1930
10
0030
15
0530
20
1030
25
1530
30
2030
x
0053
40
0630

Results of the tests conducted on motors containing composite propellant are considered inconclusive, primarily because the heating rates were too high. It was noted, however, that auto-ignition did occur as low as 314°F in one instance.

The tests on motors containing double base propellants show that the reaction in the propellant is sufficiently accelerated at temperatures above 200°F to be self-sustaining. No tests thus far have indicated that this condition exists below 200°F.

A survey of reports on solar radiation studies conducted at White Sands Missile Range indicates that there is little probability that rocket motors will experience internal temperatures of 200°F or above under any normal storage or handling conditions.

Tests conducted at White Sands Missile Range in July and August, 1960, produced data showing temperatures measured inside a steel shipping container painted standard olive drab. These were 115 to 136°F. Temperatures measured on the surface of the motor case ranged from 104 to 121°F and temperatures on the surface of the propellant inside the perforation were 100 to 114°F. Temperatures on the surface of the containers ranged from 138 to 174°F.

A survey of auto-ignition temperatures reported for some of the more recent propellants shows that many ignite at temperatures of 465 to 700°F after 5 seconds in a wood's metal bath. Some of these propellants also ignited at 400 to 410°F in five hours, and one ignited after approximately one hour (61.5 min) at 345°F.

From the results of tests conducted thus far and from a review of published data, it can be concluded that:

1. Temperatures likely to be experienced in normal storage and handling are not high enough to cause auto-ignition in solid propellant motors currently in production.

2. Slow application of heat or extended storage at temperatures of 200°F or higher may produce auto-ignition and violent explosion in solid propellant rocket motors and Jatos.

3. Auto-ignition may be experienced at a lower temperature if heat is applied slowly than if it is applied rapidly.

It is recommended that propellant manufacturer's conduct laboratory testing to establish the minimum temperature at which an exothermic reaction is generated which will lead to ignition and/or the minimum temperature at which new formulations can be auto-ignited by the gradual application of heat or by long term storage.

References

White Sands Proving Ground Technical Memorandum 177, "Effects of Rifle Fire, Flame, Slow Heat, Blast, and High Order Detonation on The Loki Motor," C, August 1954.

White Sands Proving Ground Technical Memorandum 268, "Hazards Tests of Double-Base Propellant Grains and Jatos," C, October 1955.

Propellant Powder Manual, SPIM-2, C, Solid Propellant Information Agency, Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.

White Sands Missile Range Data Report 1-60, "Hawk Open Desert Storage Solar Radiation Test" C, January 1960

Bell Telephone Laboratories, Inc., White Sands Laboratory, Memorandum for File "Nike Hercules - Effects of Solar Radiation on Missile Temperatures" Case 27675-2.

Col. Hamilton: Our next speaker is Mr. Wm. R. West, Process Development Engineer for the Grand Central Rocket Co. who will give us a presentation on "Safety Precautions in Mixing and Processing of High Energy Propellants."

Mr. West: Thank you Colonel. Good morning gentlemen. By way of introduction, my background is that of a Process Engineer, not as a Safety Engineer. However, safety in all of its aspects is very dear to my heart. My subject involves propellant formulations which are classified Confidential. Please consider this portion of my presentation as Confidential.

Introduction

Complete development of high energy solid propellant involves more than the development and optimization of a propellant formulation to meet the required ballistic and mechanical properties of the end item. Although this one task in itself can, and many times does involve a costly and time consuming effort, the complete propellant development program must include above all else the development of safe and practical methods of mixing and processing: (a) the components of a propellant formulation; (b) combinations of these components, and (c) the mixed propellant in the "liquid" and "solid" state.

My presentation this morning is concerned with this latter subject and is titled "Safety Precautions in Mixing and Processing High Energy Solid Propellants." Because our time is limited, I have chosen not to cover as broad a subject as the title suggests. Rather I have narrowed the subject to a specific example of safety precautions taken at Grand Central Rocket Co. in mixing and processing a newly developed nitroplastisol propellant. In this manner the presentation will involve more specific rather than general information and can be completed in the time period allotted.

Background

To provide you with a little more background to the problem, I shall describe briefly what the propellant formulation includes and why and how it is developed. Figure I shows the new formulations as Propellant X. For proprietary reasons I have coded the plasticizers and stabilizers. Formulation A, shown in Figure II, was used as starting point for Formulation X. Considerable experience and data were available on Formulation A.

FIGURE I

PROPELLANT X FORMULATION

COMPONENT	FUNCTION	WT. %
Plasticizer P_1 (nitrated)	fuel - oxidizer plasticizer	32.00
Plasticizer P_2 (nitrated)	fuel - oxidizer plasticizer	
Stabilizer S_1	stabilizer	1.00
Stabilizer S_2	stabilizer	
Fluid Ball Powder (8% NG)	fuel - binder	15.00
Aluminum H-5	fuel	17.00
Ammonium Perchlorate (unground)	oxidizer	26.00
Cyclotetramethylene tetranitramine (HMX)	oxidizer	9.00
		100.00

STANDARD SAFETY TESTS ON CURED PROPELLANT

(1)	Impact sensitivity (50% with 2 Kg wt)	30 cm.
(2)	Autoignition	415°F.
(3)	Taliani, time to 100 mm Hg. approx. slope to 100 mm, $\frac{\text{mm Hg}}{\text{min.}}$	200 min. 0.43
(4)	Card gap detonation, 50% level in.	1.1

FIGURE II

PROPELLANT A FORMULATION

COMPONENT	FUNCTION	WT. %
Plasticizer P_1 (nitrated)	fuel - oxidizer plasticizer	33.00
Stabilizer S_1	stabilizer	1.00
Fluid Ball Powder (8% NG)	fuel - binder	15.52
Fluid Ball Powder (23% NG)	fuel - binder	0.48
Aluminum 1-131	fuel	18.00
Ammonium Perchlorate (Ground)	oxidizer	31.68
Tricalcium Phosphate	anticaking agent & slope depressant	0.32
		100.00

STANDARD SAFETY TESTS ON CURED PROPELLANT

(1)	Impact sensitivity (50% with 2 Kg wt.)	19 cm.
(2)	Autoignition	326°F.
(3)	Taliani, time to 100 mm Hg.	—
	slope to 100 mm Hg, $\frac{\text{mm Hg}}{\text{min.}}$	—
(4)	Card gap detonation, 50% level, in.	2.25

The Problem

Formulation X was initially conceived, evaluated, and optimized by the propellant chemist, who carried out this work with small scale batches under his careful control. From the initial concept of this formulation the propellant chemist considered the following safety features:

(a) Toxicity of ingredients
(b) Thermal stability of ingredients
(c) Impact and shock sensitivity of ingredients
(d) Electrostatic sensitivity of ingredients
(e) Compatibility of ingredients

However, a complete evaluation of these features was not justified, provided the small scale work could be accomplished safely, until the formulation was deemed a desirable candidate for full scale development. Having reached this stage with Formulation X, the problem remained how to mix and process this formulation in a safe and practical manner on a full scale.

The General Approach

To answer this problem, the following general approach was used:

(a) A detailed and systematic plan was outlined to evaluate impact sensitivity, critical diameter (by card gap test), and thermal stability of the ingredients and their various combinations. Specific objective of this study was to determine on a laboratory scale the safest and most practical order and manner of ingredient addition. Figure III shows this plan.

(b) At the completion of studies outlined above a series of proof tests were planned to evaluate this mixing and processing technique on a pilot plant scale. Special safety precautions planned and available in the pilot plant were:

(1) Location of pilot plant area isolated from other propellant operations which has the advantage of:

a. Minimum number personnel required in immediate and near area.

b. Less hazard of charge to charge propagation to detonation.

c. Less chance of waste propellant contamination.

FIGURE III

PLAN OF EXPERIMENT
LABORATORY SAFETY TESTS
ORDER & MANNER OF INGREDIENT ADDITION

Ingredient or Combination of Ingredients	Type of Test		
	Impact Sensitivity	Card Gap	Thermal Stability (DTA)
TESTS FOR PERSONNEL SAFETY			
Plasticizer P_2	x	x	x
Plasticizer P_1	x	x	x
HMX	x	x	x
FBP	x	x	x
AP	x	x	x
Al			
Stabilizer S_2			x
Stabilizer S_1			x
$P_1 + P_2$	x	x	x
$P_2 + S_2$		x	x
$P_2 + S_1$		x	x
$P_1 + S_2$		x	x
$P_1 + S_1$		x	x
$P_1 + P_2 + S_2$		x	x
$P_1 + P_2 + S_1$		x	x
$P_1 + P_2 + S_1 + S_2$	x	x	x
$S_1 + S_2$			x
AP + HMX	x	x	x
AP + FBP	x	x	x
AP + HMX + FBP	x	x	x
HMX + Al	x	x	x
HMX + FBP	x	x	x
HMX + Al + FBP	x	x	x
Al + FBP	x	x	x
Formulation X (uncured)	x	x	x
TESTS FOR EQUIPMENT PROTECTION			
$P_1 + P_2 + S_1 + S_2$ + FBP	x	x	x
$P_1 + P_2 + S_1 + S_2$ + FBP + Al	x	x	x
$P_1 + P_2 + S_1 + S_2$ + FBP + Al + AP	x	x	x
Formulation X (uncured)	x	x	x

(2) Remotely operated and air driven Lightning Mixers with no submerged bearings.

(3) Remotely operated and air driven Syntron feeders for remote addition of dry components.

(4) Polyethylene mix containers with wide clearance to stainless steel mixer impeller.

(5) Humidity and temperature controlled mix bay.

(6) A remote and well protected control room.

Detailed Plan

Laboratory Study - Order and Manner of Ingredient Addition

Referring to Figure III, I shall describe briefly why this study was planned in this manner. Formulation X has eight (8) components. The total number of possible combinations of components is 2^8-1 or 255. Clearly a study of this number of combinations would be costly and time consuming. To reduce this number of combinations studied some logical restraints were applied. These restraints were:

(1) From a practical consideration the plasticizers and stabilizers must be combined before addition of other components for the stabilizers to dissolve effectively in the plasticizers. However, the method of combining these four components should not be restrained.

(2) To obtain good mixing solids must be added to liquids.

(3) Based on known safety hazards, all combinations which involve dry mixtures of ammonium perchlorate and aluminum must be avoided.

(4) Major emphasis should be placed on the study of components and combination of components where personnel exposure is involved.

(5) Where only equipment exposure is involved, only those combinations required by laboratory procedure should be studied initially.

When these five restraints are applied to the study, only the 25 combinations shown remain.

The choice of laboratory safety tests was limited to three:

(1) Impact sensitivity

(2) Card gap test

(3) Differential thermal analysis (DTA)

Although electrostatic sensitivity and friction sensitivity test data were desirable, it was felt that the three tests chosen would provide the best basis for the preliminary screening study. HMX was known to be electrostatic sensitive, and proper grounding of both personnel and equipment was deemed essential.

The impact sensitivity tests were run on a test apparatus designed by Bureau of Explosives with one modification, the use of a solenoid switch to release the 2 Kg. weight. Samples were prepared to dimension of 0.20" diameter by 0.075" deep. The specimen was then placed in the cup of the anvil housing, and the cap and striker assembly placed in position for test. The height bar was set at desired height in cm. After the safety shield was placed in place the weight was allowed to drop by actuating the solenoid mechanism to release the weight. The values reported are the heights at which 50% detonations were experienced. Values reported are considered reproducible to ± 4 cm. based on confirming tests.

The card gap tests were determined with an assembly developed by NOL. I had originally intended to use a model to describe this test vehicle, but from sitting in the back of the room yesterday I am sure it cannot be seen there. Since I am sure Dr. Noonan has covered this subject rather thoroughly, I shall describe it only briefly.

The card gap used consisted of the following basic parts:

(1) A detonator with lead wires.

(2) Tetryl pellet donor, 2" OD x 2" L.

(3) Cellulose acetate attenuating disks 2" OD x .01" lg (when used)

(4) An acceptor sleeve 1.537 ID x 1.875" OD x 5.5" L cold rolled steel.

(5) A witness plate 4" x 4" x 0.375 mild steel.

(6) Sample contained in acceptor sleeve.

(7) Cardboard tubes containing (1) thru (4) and (6)

The sample size used was quantity required to fill the acceptor sleeve. If any of you are interested, I will be happy to show you the model.

For all card gap data shown in Figure IV, no attenuating cellulose acetate disks were used, i.e., 0 gap. Only one determination was made for each combination. As used then, the test can provide only the following results:

Result		Conclusion
	(a)	Critical dia. < 1.5"
"Go"	(b)	Estimate of detonation order (high or low order)
"No-Go"	(a)	Inconclusive

Although no ranking of the combinations is possible, the value of the tests lies in establishing whether critical diameter of the combination is less than 1.5". In addition, these first tests provide a guide for follow up tests using attenuating disks, which then can be used to rank the combinations.

The Differential Thermal Analyses were accomplished on an instrument built at GCR. The system consisted basically of two glass tubes, a reference tube and a sample tube, located in an electrically heated furnace. Heating rate of the tubes was controlled to attain a constant rate, 4-5°F temperature rise/minute. The tubes were 13mm dia. x 50mm long. The reference tube contained glass beads while the sample tube contained the sample mixed with glass beads in a 1 to 4 weight ratio.

Copper constantan thermocouples were used to monitor temperatures within the reference tube and within the sample. Two recorders were used in conjunction with a thermocouple EMF balance system to record sample temperature and temperature differential between sample and reference tube. Sample size quantity was in the range of 400 to 500 milligrams. With this system it was possible to measure temperature at which exothermic and endothermic reactions were initiated and peak temperatures attained.

Results

Figure IV summarizes data obtained on laboratory safety tests to date. Unfortunately, card gap sensitivity data with attenuating cellulose acetate disks and part of the impact sensitivity data were not completed in time for this presentation. However, some interesting and significant inferences can be drawn from data that are available. Referring to Figure IV, the values of impact sensitivity for the

FIGURE IV

SUMMARY OF LABORATORY SAFETY TESTS
ORDER & MANNER OF INGREDIENT ADDITION

Ingredient or Combination of Ingredients	Impact Sensitivity cm/2 Kg wt.	Type of Test: Card Gap (0 Gap) "GO"	"NO GO"	ORDER	Thermal Stability DTA, °F. BEGIN OF EXO-	DETONATES YES	NO
TESTS FOR PERSONNEL SAFETY							
Plasticizer P_2		x		H.O	310		x
Plasticizer P_1		x		H.O	325		x
HMX	13	x		H.O	400		x
FBP		x		H.O	310	x (355)	
AP	60	x		L.O	680		x
Al							
Stabilizer S_2			x		no exo.		
Stabilizer S_1			x		"		
$P_1 + P_2$	>100	x		H.O	310		x
$P_2 + S_2$		x		H.O			
$P_2 + S_1$		x		H.O			
$P_1 + S_2$		x		H.O			
$P_1 + S_1$		x		H.O			
$P_1 + P_2 + S_2$		x		H.O			
$P_1 + P_2 + S_1$		x		H.O			
$P_1 + P_2 + S_1 + S_2$	>100	x		H.O	308		x
$S_1 + S_2$			x				
AP + HMX	18	x		H.O	530		x
AP + FBP		x		H.O	310		x
AP + HMX + FBP		x		H.O	320		x
HMX + Al		x		L.O			
HMX + FBP		x		L.O	320	x (390)	
HMX + Al + FBP		x		L.O	320		x
Al + FBP		x		L.O	305		x
Formulation X (uncured)	8	x					
TESTS FOR EQUIPMENT PROTECTION							
$P_1 + P_2 + S_1 + S_2$ + FBP	50	x		H.O	305	x (395)	
$P_1+P_2+S_1+S_2$+ FBP+Al	>100	x		H.O	325		x
$P_1+P_2+S_1+S_2$+FBP+Al+AP	9	x		H.O	320		x

combination of the plasticizers ($P_1 + P_2$) and for the combination of the plasticizers plus stabilizers ($P_1 + P_2 + S_1 + S_2$) are greater than 100 cm. When fluid ball powder (FBP) is added to the system the combination ($P_1 + P_2 + S_1$ + FBP) has an impact sensitivity of 50 cm. The addition of aluminum to provide the combination ($P_1 + P_2 + S_1 + S_2$ + FBP + Al) gives an impact sensitivity of greater than 100 cm. However, upon the addition of ammonium perchlorate to provide the combination ($P_1 + P_2 + S_1 + S_2$ + FBP + Al + AP) gives an impact sensitivity of 9 cm. Addition of HMX to complete the Formulation X in the uncured state gave an impact sensitivity of 8 cm. This result was a distinct surprise since impact sensitivity on uncured Formulation A is 48 cm. This low value with uncured Formulation X caused us to do a complete reappraisal of test program. However, I will discuss this in more detail after reviewing the results of Figure IV.

Results of card gap tests with 0 gap were all "Go" tests with the exceptions of the tests on S_1, S_2 and the combination S_1 and S_2. Also in all instances where P_1 and P_2 were present the detonation was high order ($>$ 5000 meters/second). Combinations of AP with HMX and FBP were all high order detonations. However, the addition of aluminum or FBP or both to HMX modified detonation from high order to low order. All "Go" results were interpreted as defining critical diameter of the combinations as 1.5 cm. or less based on these tests.

Figure IV also shows some interesting results from the thermal stability (DTA) tests. In general all materials were stable to at least 300°F. At about 310°F FBP, P_2, and $P_1 + P_2$ and $P_1 + P_2 + SS_1 + S_2$ begin to exotherm. However, FBP exothermed to about 355°F when it detonated. Combinations of Al and AP with FBP both as dry mixtures and mixed with the plasticizer + stabilizer system tend to suppress the transition to detonation, although the combinations do exotherm. As mentioned earlier, the low values of impact sensitivity with Formulation X compared to Formulation A in the uncured state caused us to reappraise our laboratory test plan. Figure V shows some additional impact tests comparing these formulations with different sources of ammonium perchlorate. Note that Formulation A is sensitive to ammonium perchlorate particle size whereas Formulation X is not. Note also that combination of P_1 + AP (unground), P_2 + AP (unground), P_1 + AP (unground) + HMX, and P_2 + AP (unground) + HMX have about the same order or magnitude of impact sensitivity. Work is still in progress to resolve the cause for low impact sensitivity on uncured Formulation X.

Although data are still too limited to draw firm conclusions, the following inferences are apparent:

FIGURE V

ADDITIONAL IMPACT SENSITIVITY TESTS

COMPARISON OF FORMULATION X WITH FORMULATION A
UNCURED

Combinations	Impact Sensitivity (cm/2 Kg. Wt.)
Formulation X (unground oxidizer)	9
Formulation A (unground oxidizer)	8
Ampot Oxidizer	
Formulation X (ground oxidizer)	9
Formulation A (ground oxidizer)	57
Ampot oxidizer	
Formulation X (unground oxidizer)	9
Formulation A (unground oxidizer)	11
Pennsalt Oxidizer	
Formulation X (ground oxidizer)	9
Formulation A (ground oxidizer)	48
Pennsalt Oxidizer	
P_1 + AP (unground ampot)	13
P_2 + AP (unground ampot)	8
P_1 + AP (unground ampot) + HMX	8
P_2 + AP (unground ampot) + HMX	7

(1) The addition of AP to Formulation X for some reason unknown as yet gives a low impact sensitivity value of 9 cm for a 2 kg weight.

(2) Substitution of ground AP for unground AP does not change the impact sensitivity of uncured Formulation X as it does in the case of Formulation A.

(3) The reason for low impact sensitivities with Formulation X are not known, but it appears associated with combination of AP with the plasticizer P_1 or P_2.

(4) All combinations of ingredients tested except S_1, S_2, and S_1 and S_2 gave "Go" results with 0 gap card test. These results indicate critical diameter for these "Go" result combinations must be 1.5 in. or less.

(5) Thermal stability tests (DTA) indicate all ingredients and combinations of ingredients are stable until a temperature of 300°F is attained. At about 310°F FBP begins to exotherm and continues to exotherm to 355°F when it detonates. Combination of Al and AP with FBP both as dry mixtures and mixed with the plasticizer and stabilizer system tend to suppress the transition to detonation with FBP, although the combinations do exotherm.

Future Plans

(1) Additional card gap tests are planned with cellulose acetate spacers as outlined in the original plan.

(2) A systematic study to identify the cause of low impact sensitivity with Formulation X will be accomplished and we are confident the Formulation can be modified along with processing technique to give an acceptably safe system.

(3) Deflagration to detonation studies on a scale greater than critical diameter will be run to determine whether drop tests really indicate a detonation or fire hazard.

Col. Hamilton: Questions gentlemen?

Dr. Ball: I'm kind of surprised that some of your bimary systems showing up these low gap test results and would like to point out in line with the Thiokol paper of the other day, that you can't be satisfied with a bimary system of just composition unless you're sure that you're not going to get other combinations of those two bimaries. We know that for sure HMX and aluminum will go high order in some ratios of one to the other, and if you happen to have in your overall composition a proportion of those things that

won't go you might be real lucky, but as far as processing goes you still have to assure yourself that you're not going to go through other ratios of those few things on your bimary systems.

Mr. West: I agree wholeheartedly Dr. Ball. The test as originally outlined involved the ratios of the component only as specified in the formulations. This is a very crutial part of the study which we planned, the actual effective transition composition that you can go through by the addition of components and we don't intend to neglect it before we get through.

Mr. Richards: You mentioned you were concerned about the 8 centimeter reading and that you plan to change the formulation before you go into the pilot plant. What would you consider as a safe reading on impact sensitivity to go into pilot work?

Mr. West: To answer your question, I'd like to qualify it. I don't think that we can base a decision on going into the pilot plant strictly on one value or a particular test. I'm not trying to avoid the answer to your question. I would say this much though, that with the value of around 8 centimeters, we're reticent to go much further until we resolve based on a completed evaluation of this test plus other tests whether we can go in and safely process it on a pilot plant scale. It has us worried, I'll put it that way. I think even around 20 centimeters would begin to start looking askance at it. That's just a personal feel. This is just again based on one test and as I mentioned earlier, the limitations of the impact sensitivity tests are well known. The application of these tests to practical points where you draw the line is even tougher. I think that we're all quite familiar with this. So I say that we're real reticent to process the material with this data to date in the full scale until we know our system better. Did I answer your question satisfactorily?

Mr. Richards: Yes you did. Thank you.

Col. Hamilton: Thank you very much Mr. West. Our next speaker will be Mr. L. J. Ullian, Air Force Missile Test Center, who will present "Safety and Design Considerations for Static Test and Launch Facilities for Large Space Vehicles."

Mr. Ullian: This is Confidential. My purpose today is to cover the subject of the criteria for safety and design considerations for large space systems. In the end of May President Kennedy said we're going to the moon and this pushed up the planning factors for these large systems of the Nova and larger Saturn types from the 1975 time period to today. With the development of these systems from 3,000,000 to 50,000,000 pounds of thrust and the related spacecraft, the operational safety and design problems increased by many orders of magnitude. They have come into an area where there has been very little work done, where the problems are in many cases different, where the hazards and the hazard radii instead of being blast, in some cases become accoustic. When this mission was given to NASA and to the Air Force with NASA as the general overall manager, a group was called together and I was one of these. I'd like to give credit to Mr. Bill Lawrence from Edwards, the Chief of the Test Division there and Mr. Bob Body from NASA under Dr. Devis, LOD and also to many other people. Dr. VonGurky from the ASD, to Newmark and Hanson and Dr. Silverman in Toxicity and many other people that contributed to this. Also to the Armed Services Explosives Safety Board, DIG for Safety and other people both Army, Navy and Air Force and NASA.

The hazards associated with the launch and static test of these large space systems will be blast, accoustics, fragmentation, fire and radiation. Briefly the vehicles I'm going to describe in overall terms and also the combination and weight of propellants. These are general, the actual configurations of the vehicles are still being worked on. This information will become available within the next couple of months.

First we start with the Saturn C3. This vehicle's approximate weight of propellant will be 2,500,000 pounds. An all liquid vehicle, the first stage weight of propellant of about 1,600,000 pounds with upper stages totaling about another 1,000,000 pounds of propellant.

Another C3 that has entered the picture is the C3 solid. This vehicle is a lower stage with solid propellant totalling about 3,000,000, and an upper stage with about 1,000,000 pounds.

An intermediate vehicle of about 7,000,000 pounds of thrust is also being considered. This one has in the neighborhood of 4,000,000 pounds of solid propellant in the first stage with equivalent amounts of about 1,000,000 to 1,500,000 pounds of liquid propellant in the upper stages.

The Nova vehicles that are being considered are 12,000,000 pounds, 21,000,000 pounds, 37,000,000 pounds, and 50,000,000 pounds of thrust.

Again as I say, these are just general configurations, they are not optimized. In these areas, we're talking with liquids in the range of approximately 12 to 15,000,000 pounds of propellant. We're talking in the solid range between 6 and 10,000,000 pounds of propellant in a single system.

The other system that is being considered is Nurva. This is a nuclear upper stage with about 500,000 pounds of hydrogen as a fuel. The fuels and oxidizers that are being considered are solid propellants, LOX, hydrogen, RP1. I would say these are all at the present time, although we are considering some of the toxic propellants for upper stage in the spacecraft for return missions from the moon.

Before I go into the criteria that were established by this group, I might say that we tried to take all the best and known data in the country that we could find and then extend it into the unknown or the beyond, somewhere near the moon, I'm afraid. We realized there were many holes in the data - there are many areas in which our knowledge is strictly theoretical and there's no data to back it up. This was one of the jobs of this group, to point out and find which areas would have to have concentrated study and collect some data so that we could find that our theoretical approaches are valid. When I give you the criteria later on, please realize that this is the first cut at it. There will be a program both within NASA and Air Force established to find out whether the theoretical approaches and whether the numbers the group came up with are valid and if they aren't what are the correct number.

Before I go any further, I have two movies that I'd like to show you. These are of accidents and incidents during launching of missiles at the Atlantic Missile Range, Cape Canaveral. These give you some idea of the type of incidents that can be expected from the launching and also give you some idea of the difficulty and different types of problem that we have as the user compared to the manufacturing and static test where you can keep the thing under control.

(Mr. Ullian then narrated the films)

Very briefly I'd like to give you some of the criteria that came out of this group that is being considered and in all probability will be used as criteria for siting the National Lunar Program

for large space systems. First of all we take blast - I'd like to make a statement here on blast - you will find that the criteria that we are using are much more conservative than those used at operational sites and called for in the Ordnance Safety Manual or Air Force Tech Orders. The reason for this, I think you can see partly in our film. When we launch these birds, say we have a 2,000' inhabited building distance for TNT equivalency, our range safety experience tells us that this is usually the minimum limit that we can catch this bird. In other words, the electronic and human time element involved, the bird can get as far as 2,000' away from the launch pad before we can destroy it. This means that if we site at inhabited building distance of 2000', we could land this bird right on top of it or somewhere near it and therefore this 2000' is meaningless except to add this on to our range safety considerations. So for this reason and other reasons which I'll explain, our blast limit from the controlled being Government owned land, is .2 psi. This being the limit and all the information we could get from DASA, AEC, BRL and other sources at which the majority of the window damage will occur. In other words, below this you will get some random window breakage, but the majority of the window breakage will occur at psi levels above .2, so this was picked as the limit line. Four tenths psi has always been and is still being considered the limit for non-essential personnel during evacuation of the launch danger area for missiles and on to this .4 will be tacked this 2000' range safety distance. It turns out that in the large thrust vehicle, the acoustic radii far overshadows the blast radii. In reference to what Mr. Thibodaux from NASA said, in the last few months people have been coming around saying you need 15 to 30 miles for acoustics. We agree that you don't need this much but we do feel based on the known information and also the fact that there is much unknown about acoustics and because of the phenomena that exists in that as we increase the sources for overall sound pressure levels, the frequency spectra shifts into the subaudible range from 2 to 37 cycles. By doing this we end up coming very close to some of the response characteristics of our buildings, of our instrumentation and also possibly of people.

There has been absolutely no work, at least none that we can find out or that Dr. VonGierke or Beranek & Newman could supply us with in the low frequency sound spectra for decibel ranges of 178 to 180 db in overall sound pressure levels. For this reason and for others which, since I am pressed for time, I will not go into now, the acceptable overall sound pressure level for the uncontrolled area was established at 120 db. This is higher than is recommended for aircraft, for continuous noise, but we know that the launch rate of these missiles will be one or two a month. We feel that this type of launch rate plus the fact that the community wherever this is sited, should be tied very closely to this program both

economically and by the fact that many of the people will actually be working wherever the site is, we can permit 120 db once or twice a month and not get complaints. We also feel - and again we do not have data to substantiate this - that in this low frequency range, we have given ourselves some sort of cushion for window breakage, plaster cracking and this type of thing. Our legal people can accept some claims, but of course they do not want to be plagued with damage claims from the civilian populace. Radiation-wise, we're talking of possible nuclear systems, here we're going to use the national conference of the AEC. Their limits will put us out about eight miles, if we use a nuclear system. In other words, we'll have to have about eight miles between the launch pad and the uncontrolled area.

Briefly, also I might mention fire and fragment. The initial fireball radius, we assume to be 750'. This is based on some AEC tests. For plugging this in with some tests and particularly the liquid systems at the Cape, we will probably increase this to 2000' for the fireball radius. Fragment radius -and this again is based on fragmentary data based on Minuteman tests, Polaris tests, both destruct system and detonation tests, deflagration tests and also our own experience at the Cape - at the present time established a 1 mile limit. We feel we may have to increase this somewhat based on some new data and re-evaluation of data at the Cape. What we're saying here about fragmentation is we're accepting a certain probability level. This level is the same that we accept for over-fly which is 10^7. We still realize that this does not take care of all fragments and that light fragments such as missile skins which are promiscuously carried by the wind, can land, of course, as far as 4 or 5 miles away, particularly if the missile is say at an altitude of 10,000 ft. when it's destroyed or when the incident occurs.

I'm going to take a few representative vehicles since I do not want to get into the actual vehicles themselves although these are fairly close to the general vehicles - they're not optimized - and give you some of the distances that these criteria lead to. If you are interested in the method and approach used to obtain this data, you may contact me or Mr. Body from NASA at Huntsville, or Mr. Lawrence at Edwards.

For the Saturn C-3, 3,000,000 pounds of thrust, the limit to the uncontrolled area is probably the most important because this tells you how much land you have to buy to site this. The figure is 16,000 ft. to the .2 psi line.

One other thing I might mention that I forgot. We assumed 10% equivalency for LOX-RP1 because all these systems have more

than 500,000 pounds of propellant. For less than 500,000 pounds of propellant, we assume 20%. For the LOX hydrogen system there have been no large scale tests although Air Force and NASA are now jointly conducting a large scale spill test of 40,000 pounds. Until we get the results of these tests, we are using 60% based on the study by Arthur D. Little of the Centaur missile. We are using a total propellant weight of 60% of this for a TNT equivalency and then going into the overpressure calculations.

I would like to talk just a few minutes about solid propellant motors. We are saying that they will have to be Class 2 storage items. We feel after our studies that if you have Class 9 storage problems then the operational problems will probably price you out of the lunar program. This is worth thinking about and we do not mean an arbitrary or a legislated Class 2 item. We mean a tested Class 2 item. This is one area that I talked to Dr. Noonan about and some other people and we feel we're not sure yet what tests we mean because we think possibly for storage and until you get them on the launch pad, we can use the same type of hazard test we've used in the past. For launching at the present time, we are considering 20% support from a Class 2. This is based only on the Minuteman test, the Polaris test, with the large booster charges of 100 pounds and so on, would seem to indicate between 5 and 15% support from these Class 2 systems. This is another area in which there will have to be some work done, either with some sub-scale or full-size segmented motors. Mate them with some LOX-RP1, LOX-hydrogen, burst the LOX-RP and hydrogen containers and see what support we do get. But right now the figures I've given you are based on 20% for the solid, 60% for LOX-hydrogen and 10% for LOX-RP1. The acoustic distance for this particular missile is only 11,500 ft. to the 120 db line. If we go on to the C-3 solid-liquid combination, the first one I gave you is all liquid, 7,000,000 pounds of thrust, I'm not giving you weights here, if you are interested in weights I can give them to you later. Here we're starting to come close to the cross-over point, the acoustic hazard and the blast hazard. In this case the blast hazard for the .2 psi line is 18,600 ft. The acoustic for 120 db is 19,000 ft. Now, the Nova, all liquid - 12,000,000 pounds of thrust, becomes the cross-over point. The acoustic hazard radii for 120 db is 25,000 ft. The .2 psi line is 25,100 ft. and of course, since these aren't optimized systems, you can say the two hazard radii are equal. If we go on to the Nova solid-liquid combination, 21,000,000 pounds of thrust and this can vary all the way up to 50,000,000 pounds - but let's just take this one for now. The acoustic hazard radii predominates at 35,000 ft. or close to 7 miles. The .2 psi line is only 24,050 ft., so you can see for the larger thrust with the theoretical calculations that are available at the present time, the acoustic radii in the larger thrust missiles predominates over the blast.

Now we do have some other figures, for instance; a .4 line for launch danger area, various limits at which people can be subjected to acoustics, various limits for blast overpressure. We will probably plan our blockhouses at about the 25 psi line although this is not definite yet. We're still studying this with Newmark & Hanson and some other design people. One thing I would like to mention along with Dr. Ball's comments and that is regarding the design of structures. If we take the Ordnance Safety Manual - and I'm not downgrading it, I think it is a good manual. But if we take the table alone and try to use it, I'm afraid that in many of these cases, we could not accomplish the lunar program. What we have to do is combine this with our blast and acoustic hazards and come up with buildings that are designed to withstand dynamic overpressures and acoustic vibrations so that we can protect our people within these buildings and take them in close enough to do the electronic and electrical job that has to be done to support this type of launching for these large systems.

The other thing that is necessary and will be necessary for these large systems is to educate the public. I think that one of the most important things that can be done is educating the public on what the hazards are and that they can be controlled just as with nuclear weapons. It isn't a big black demon that can not be controlled - tell them what the problems are and what you're doing to solve them. Huntsville is doing a very good job of this right now with the Saturn firings.

Very briefly those are the conclusions we came up with. We do feel that people and equipment within the control areas can be protected by adequate design of structures. We feel that the nuclear propulsion systems under consideration now will not present any nuclear blast potential. They do present a radiation hazard. At the present time thru NASA and AEC and AFSWC who worked with us on this, we feel this radius will be 8 miles to the uncontrolled area with nobody within a 2 mile radius of the missile. We do feel probably the biggest conclusion we came out with is that there are many additional studies needed, much additional information needed and we don't have much time to get this information. We can not wait two or three or four years to get this type of information. As I mentioned in a couple of comments from the floor, these sites will be selected and they will be selected very shortly and I'm afraid it may be on the best theoretical information we have available and this is all we can hope for. (Mr. Ullian narrated a second film)

Col. Hamilton: Thank you very much Mr. Ullian. Does anyone else have anything to bring up? This concludes the meeting gentlemen. Thank you very much for participating.

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Wilson, Albert W.	Dow Chemical Co.
Wiuff, C.	Aerojet-General Corp., Sacramento, Calif.
Whitney, R. C.	DIG/Safety, Norton AFB, Calif.

DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD -
2461 EISENHOWER AVENUE
ALEXANDRIA, VIRGINIA 22331-0600

DDESB-KMC

0 7 JUL 2000

MEMORANDUM FOR DDESB RECORDS

SUBJECT: Declassification of Explosives Safety Seminar Minutes

References: (a) Department of Defense 5200.1-R Information Security Program, 14 Jan 1997

(b) Executive Order 12958, 14 October 1995 Classified National Security Information

In accordance with reference (a) and (b) downgrading of information to a lower level of classification is appropriate when the information no longer requires protection at the originally level, therefore the following DoD Explosives Safety Seminar minutes are declassified:

a. AD#335188 Minutes from Seminar held 10-11 June 1959.
b. AD#332709 Minutes from Seminar held 12-14 July 1960.
c. AD#332711 Minutes from Seminar held 8-10 August 1961.
d. AD#332710 Minutes from Seminar held 7-9 August 1962.
e. AD#346196 Minutes from Seminar held 20-22 August 1963.
f. AD#456999 Minutes from Seminar held 18-20 August 1964.
g. AD#368108 Minutes from Seminar held 24-26 August 1965.
h. AD#801103 Minutes from Seminar held 9-11 August 1966.
i. AD#824044 Minutes from Seminar held 15-17 August 1967.
j. AD#846612 and AD#394775 Minutes from Seminar held 13-15 August 1968.
k. AD#862868 and AD#861893 Minutes from Seminar held 9-10 September 1969.

The DoD Explosives Safety Seminar minutes listed above are considered to be public release, distribution unlimited.

DANIEL T. TOMPKINS
Colonel, USAF
Chairman

Attachments:
1. Cover pages of minutes

cc:
DTIC

AD # 332711

[redacted]

EXECUTIVE
RECORD COP

Classified by Chairman, DDESB
SUBJECT TO GENERAL DECLASSIFICATION
SCHEDULE OF EXECUTIVE ORDER 11652
AUTOMATICALLY DOWNGRADED AT TWO YEA
INTERVALS
DECLASSIFY ON 31 December 1973

MINUTES
of the Third
EXPLOSIVES SAFETY SEMINAR
on
HIGH-ENERGY SOLID PROPELLANTS

Held at the
Mission Inn, Riverside, California
on
8-10 August 1961

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

Armed Services Explosives Safety Board
Washington 25, D. C.

DOWNGRADED AT 3 YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS.
DOD DIR 5200.10

~~CONFIDENTIAL~~

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attendee